ASTRONOMY

September 1979

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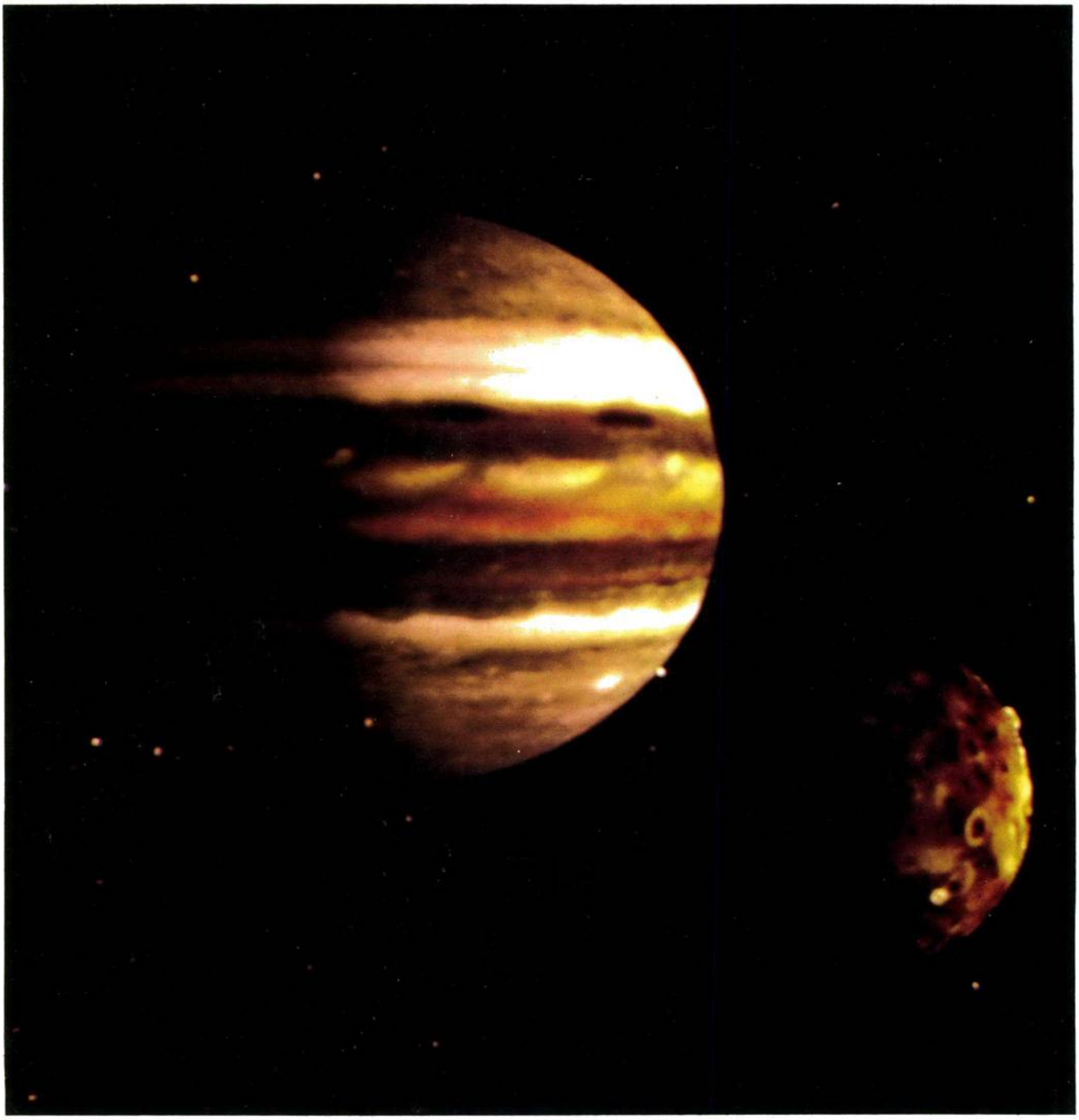
Return to Jupiter



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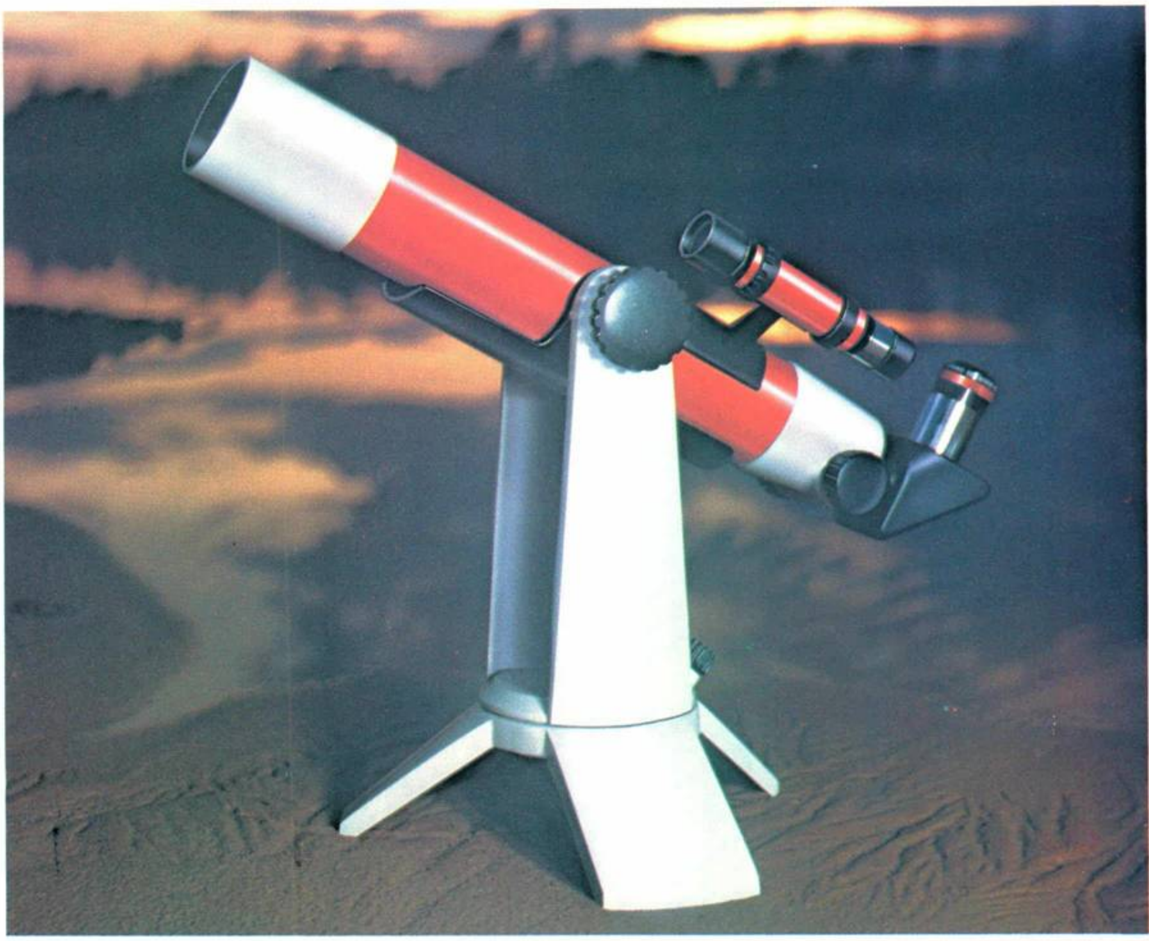

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ASTRONOMY

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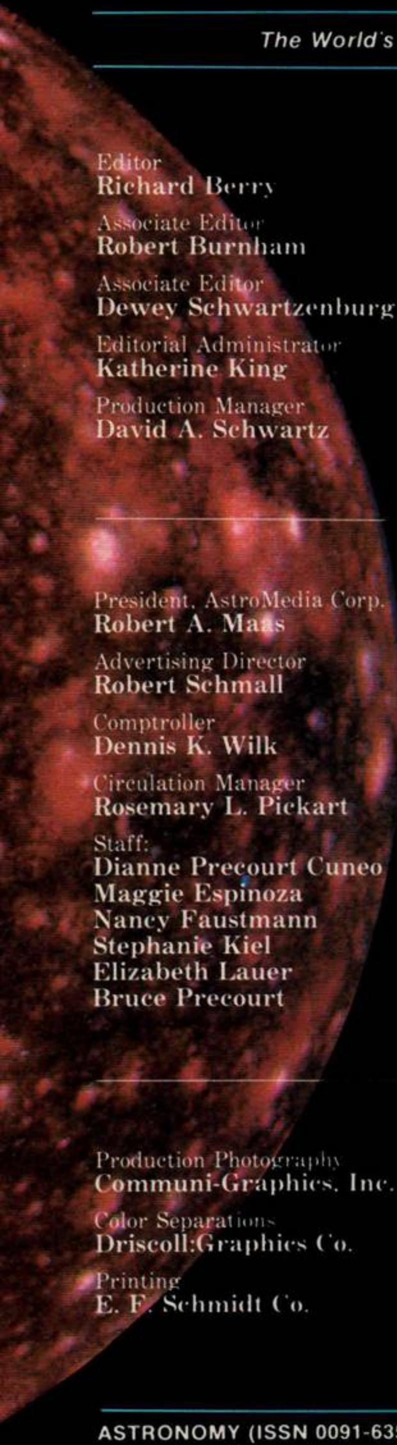

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6 Return to Jupiter
12 The Great Red Spot
20 The Jovian Clouds
Forum 24 Voyager — Why It's Important
The Discovery of Jupiter's Ring
Lusty Legends
Sky Almanac 31 The Moon in Eclipse
Photography in Astronomy 37 This is Astrophotography
Equipment Atlas 47 Visual Image Brightness
Gazer's Gazette 52 Learning to Look
Astronomy Reviews 56
AstroNews 60
Stellar Frontiers 66 Stellar Formation
In Focus 71
Astro-Mart 73
Star Dome 80 Lacerta

Cover: This dramatic moment in the Voyager 2 mission, shortly before closest spacecraft approach to Jupiter, shows satellite Io and its volcanic plumes as the spacecraft began a ten-hour "volcano watch." The scene was reconstructed by Charles E. Kohlhase and James F. Blinn, using computers at the Video Graphics Facility at the Jet Propulsion Laboratory. The spacecraft is the tiny white dot at Jupiter's limb. This page and facing: Heavily-cratered Callisto has an old surface undisturbed since the formation of the solar system. The bright areas are craters or material thrown from craters; the large ringed structure (upper left) is probably an ancient impact basin. JPL/NASA photograph.

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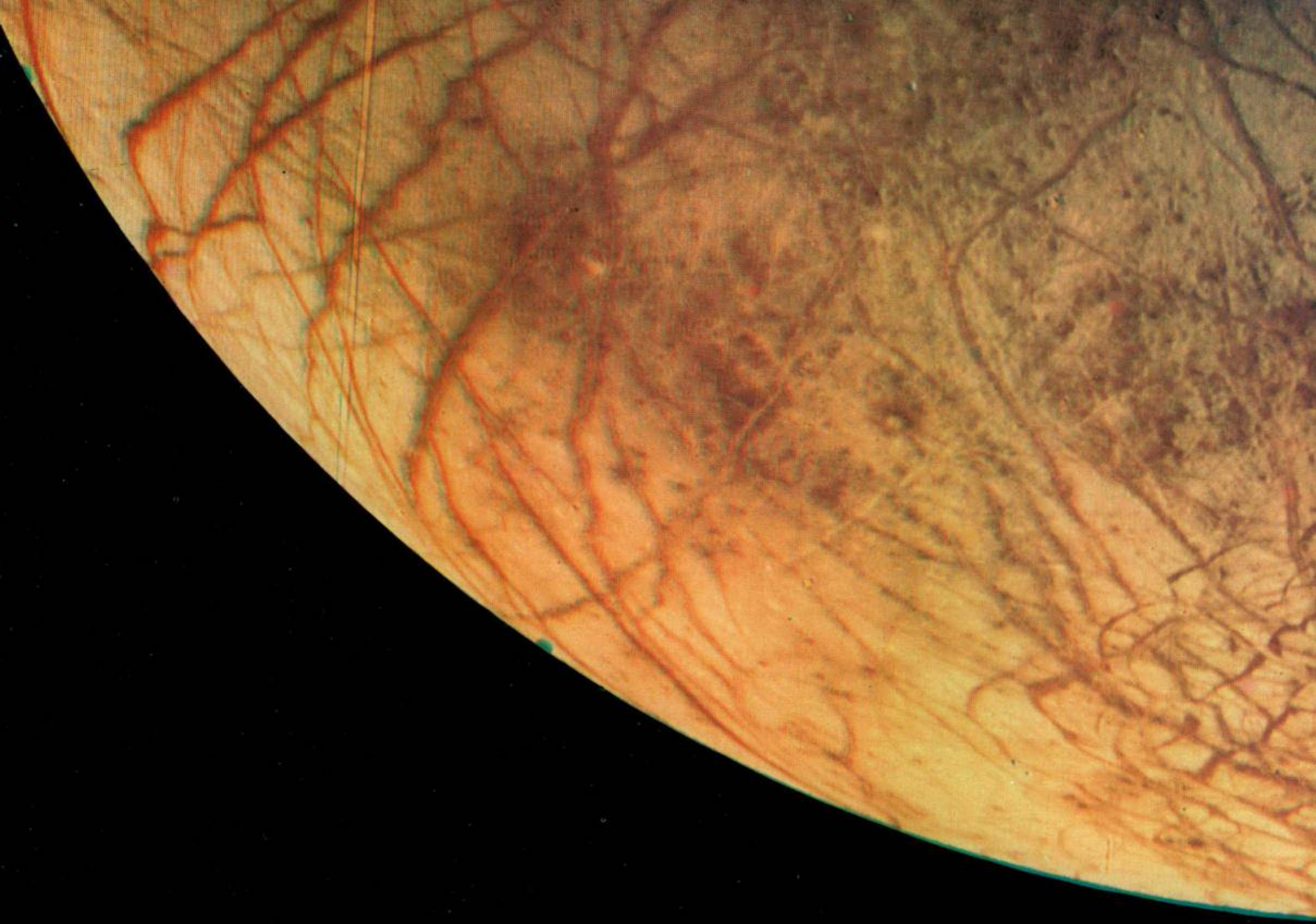
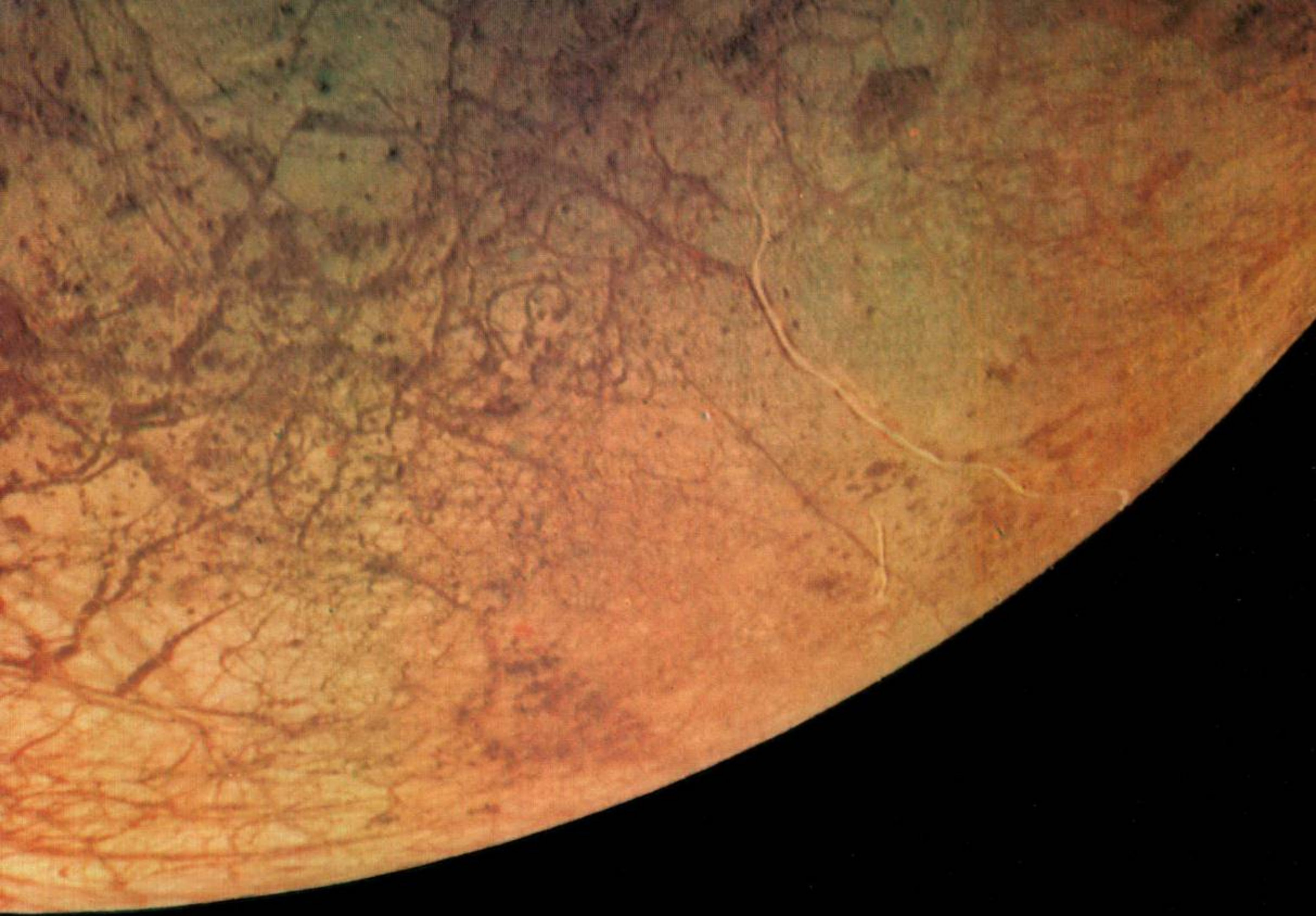


Return to Jupiter



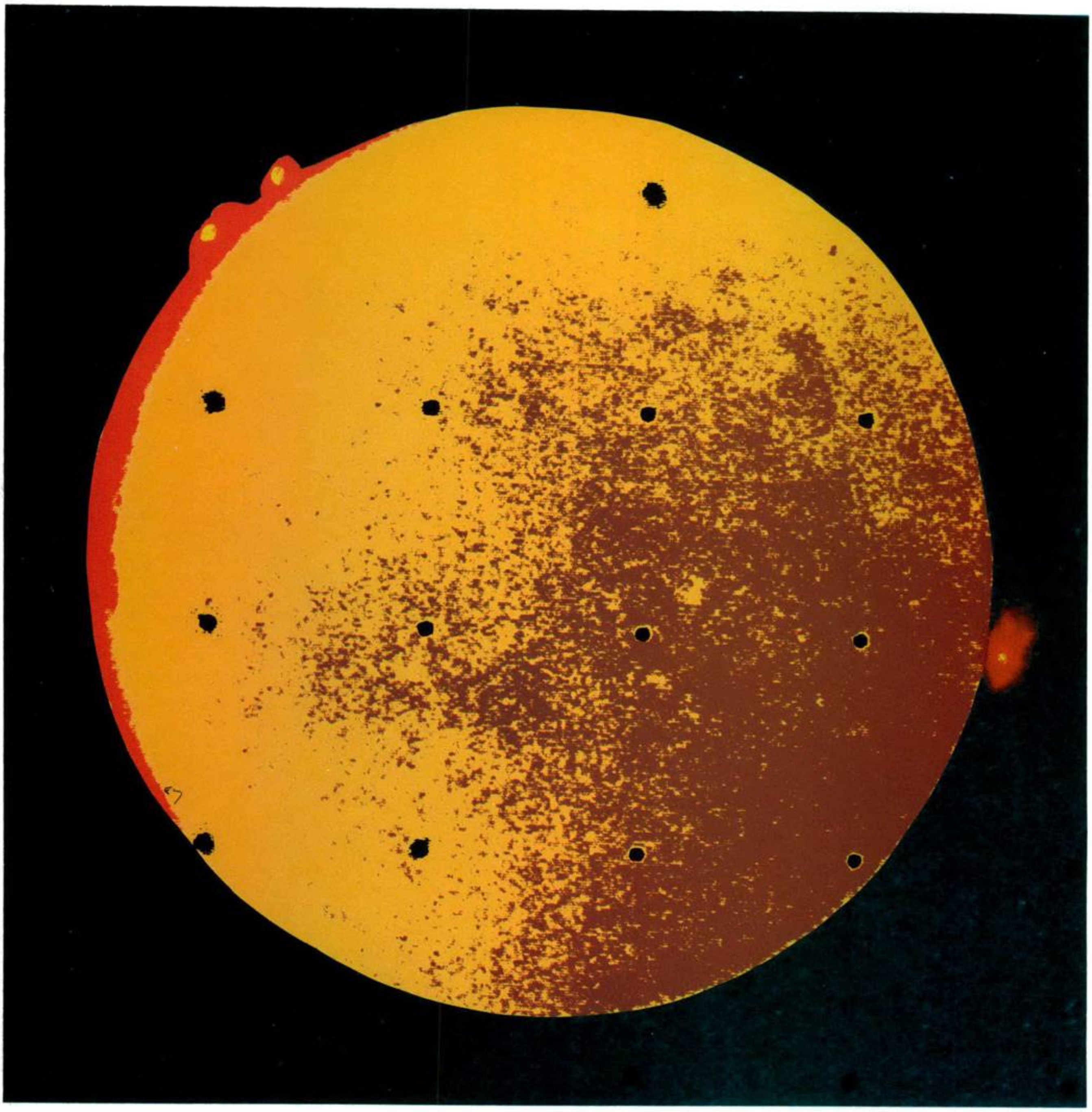
Europa's surface is covered with giant features that look like cracks, leading astronomers to suspect that a light-colored ice crust has fractured and filled from below with darker material. The cracks have almost no height or depth, despite the fact that they're several miles wide. Many of the cracks have a light stripe running down the middle. Europa's crust, made of ice many tens of miles thick, is extremely flat — perhaps the flattest in the solar system — and there are very few craters.

We can never again think of Jupiter in the classic way we have since Galileo Galilei. As a remote ball of light sporting pale cloud bands and a red oval accompanied by four "little stars," Jupiter was essentially beyond human experience. Fiction and speculation fleshed out the thin frame of scientific fact. We have now been to Jupiter, our human senses replaced by instruments aboard the twin spacecraft, Voyagers 1 and 2. Their television cameras became our eyes, their radio instruments our ears; through them we touched and tasted its charged particle environment, caught the whiff of methane, ammonia, and sulfur dioxide with their infrared spectrometers, and felt the jovian magnetic fields with their magnetometers. Voyager has taken us where our frail bodies couldn't go — into radioactive environments, into cold, unimaginable isolation, and years in space.

We can now imagine, with a reasonable claim to accuracy, what we would see, what we would feel, and what we would find if we were to fly to Jupiter. Our vision of the jovian system has become far more detailed, complete, and complex. We have explored parts of Jupiter that we knew about only indirectly, discovered phenomena that we didn't expect, and recognized that Jupiter and its satellites are an entirely new family of worlds.

Jupiter is a vast ball of liquid and metallic hydrogen. Mixed throughout the hydrogen is roughly one helium atom for each ten hydrogen atoms, a ratio that closely reflects the composition of the Sun. The stuff of Jupiter is primordial, captured and held intact — almost without loss — by the powerful gravitation of the planet. It is as perfect a sample of primordial material as we are likely to find in the solar system.

The bulk of Jupiter consists of molten (i.e., liquid) metallic hydrogen. We on Earth think of hydrogen as a gas, but under the extreme pressures found deep in this giant planet, electrons flow freely



Voyager 2 took this picture of Io during its "volcano watch" on July 10th. At left is the sunlit crescent of Io, and on the right, sunlight reflected from Jupiter illuminates the night side of the satellite. Three volcanic plumes are visible: plumes 5 (upper) and 6 (lower) are about 60 miles high, while plume 2, on the dark limb, is some 110 miles high and 200 miles wide. At least six of the seven volcanos observed by both spacecraft are still active. Plume 2 is now a time-and-a-half bigger than it was during the Voyager 1 flyby. The largest plume, plume 1, was no longer erupting during the Voyager 2 flyby.

through the material, as they do in a molten metal. Metallic hydrogen fills the inner 60% of the radius of Jupiter — a ball some 50,000 miles in diameter.

Above the metallic hydrogen lies some 18,000 miles of liquid hydrogen. Throughout this layer — an ocean of hydrogen — the temperature and pressure drop off steadily until finally, about 600 miles below the cloud tops, the hydrogen becomes gaseous, and we speak of it as an atmosphere. The visible surface of Jupiter, what we see when we look at it, consists of bands of clouds — vividly colored by tiny amounts of heavy-element impurities — swirling around the planet.

Our access to the core of Jupiter is limited to mathematical modeling and scientific guesswork. Today, the best guess about what lies at the very heart of Jupiter comes from its primordial abundance of heavy elements — the rocky materials that make up our own planet. Though these materials make up only a few percent of the entire mass of the planet, Jupiter's mass is so great (in excess of 300 Earth masses) that there would be enough to make an iron-silicate core several times the Earth's mass. Such a core would be small — only a few thousand miles in diameter — and molten.

"...it's hard for me to imagine how much we've learned...."

Orbiting Jupiter are four planets, tiny in comparison to Jupiter but significant to mankind because we live on a world not much bigger.

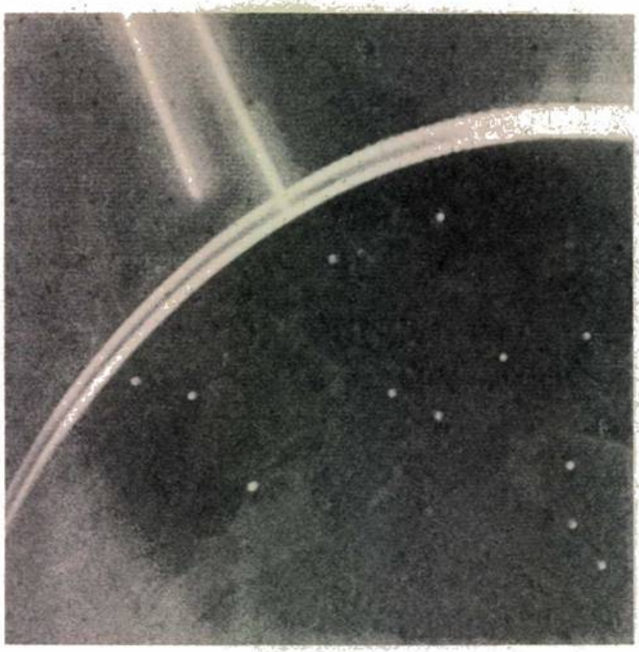
The jovian satellites have revealed how parochial our previous notion of the term "planet" truly was. With the jovian satellites we have nearly doubled the number of hard planetary surfaces that we know anything at all about. Before the Voyager missions, we knew five "small" planets: Earth, our Moon, Mercury, Venus, and Mars. Now Voyager has shown us four more worlds — Io, Europa, Ganymede, and Callisto — a whole mini-solar system more exotic than anything we expected.

In this extraordinary quartet of worlds, we see ancient cratered terrain dating back to the birth of the solar system (Callisto), a new surface formed in the four months between Voyager 1 and Voyager 2 (Io), remnants of enormous ring structures, faulting, and cratering (Ganymede), and a giant planetwide system of fractures (Europa). These bodies, taken separately and collectively, provide a vast range of new insights into a process that mankind has never seen: the formation of a solar system.

The jovian quartet contains two pairs: one pair dense and rocky, the other less dense and icy. Io and Europa, the rocky inner pair, have built themselves new crusts, and so craters are entirely absent on Io and nearly absent from Europa. The outer pair, the icy satellites, are both cratered heavily, marked by giant ringed remnants of catastrophic impacts possibly dating back to their formation. Together the four satellites display a sequence of surface features, composition, and activity that demand investigation.

Callisto, the Galilean satellite farthest from Jupiter, is pockmarked with a multitude of craters — back to back, touching, overlapping. It may be, in fact, the most heavily cratered planetary surface in the solar system. Because most cratering occurred shortly after the formation of the solar system while material was still accreting onto planets and moons and building them up, we know Callisto's surface is ancient. There are no signs of surface activity there — no telltale volcanic cones, no flows of lava, no cracks or crevasses. Callisto is a dead world, probably less active than our Moon, whose extensive early volcanism helped form its maria.

Spreading across a large fraction of the diameter of Callisto are giant concentric bull's-eye patterns. Two were discovered by Voyager 1 and a third by Voyager 2. At the center of each bull's-eye is a giant ringed "basin" — the only areas on Callisto with less than fully crater-saturated surfaces. These mark the site of large bodies impacting near the end of Callisto's formation.



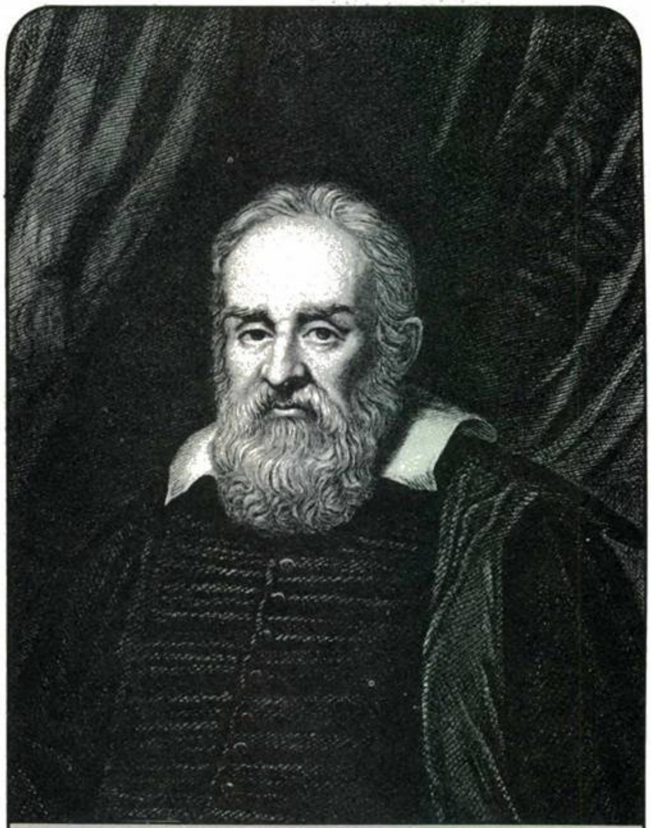
Twenty-six hours after closest approach, Voyager entered the shadow of Jupiter, swung its cameras to photograph the dark side of Jupiter, and returned this picture. It shows the limb of Jupiter curving from lower left to upper right, and the ring as a thin line arcing out of the picture, then back across and into Jupiter's shadow. The bright part of the ring is approximately 4,000 miles wide, but it may extend faintly all the way to Jupiter's surface.

Surprisingly, the great basins are not deep depressions, nor are the bull's-eye patterns much more than color differences on the Callisto surface. Callisto's low density demands that it be composed primarily of liquid water or slush with a thin rigid ice crust — possibly only a few miles thick — so weak that it cannot support the weight of a large basin or a system of concentric ridges, but instead allows them to flow out. So the bull's-eye pattern and central "basins" are visible largely because they are made of material with a different color.

But Callisto isn't quite so simple as it might appear: it's more than a giant drop of water with a frozen surface. Voyager 2 photographs show that there are regional differences in surface composition — areas of different color — as well as a class of "blue haloed" craters which apparently have turned up materials from deeper inside.

Ganymede shares Callisto's low density; hence it's probably ice-based too. The same basic model for Callisto also fits Ganymede: a liquid core with an icy crust. Yet on the surface, Ganymede is profoundly different. "We're searching for the reasons for the differences between these two bodies," said one astronomer; "we're looking for ways to turn a Callisto into a Ganymede."

Large areas of Ganymede closely resemble Callisto: they are dark-surfaced, pocked with slumped craters, and in some places crossed by giant concentric rings reminiscent of Callisto's great basins. These areas may be the remnants of Ganymede's ancient primitive crust. If anything,



An Interview with Bruce Murray
Director of the
Jet Propulsion Laboratory

Q: If Galileo walked into the pressroom of JPL today as we cover the Voyager 2 flyby, what would you say to him?

A: I would bow, or maybe kneel, because Galileo was, more than any other individual, the man who started the age of enlightenment in which we are presently carrying forth — even with Voyager at this instant. He was the man who set in motion the idea that we should understand nature as revealed through observation rather than theological principles. He, in turn, would be astounded, I believe, to realize how far we have come, how great our instruments of discovery are, and how wonderful and diversified the universe we are discovering is.

He first recognized four tiny dots of light beside the planet Jupiter which we have called the Galilean satellites and it would be a fitting memorial indeed for him to be able to see and absorb in his own mind what those objects are really like. It would be a great event for both Galileo and for us if we could have that reunion.

Q: I understand your next mission will be named after Galileo.

A: Yes, our next mission is to follow up on this one with an orbiter about the planet Jupiter, in particular to make close passages to these satellites and explore them in considerably more detail than we can with our flybys now. The fact that it will be named Galileo rather than Artoo Deetoo or Space Explorer, I think, is a marvelous testimony to the American people and to their recognition of the international character of the history of exploration.

— Ben Mayer

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the ringed basins of Ganymede are larger than the basins on Callisto — perhaps enough bigger that the impact which formed them may have triggered internal activity in Ganymede (but not in Callisto).

The Ganymede craters are "everywhere somewhat subdued or collapsed, so we're looking at a fundamentally icy upper layer that cannot support the weight of heavy uplifted crater rims, which gradually sink away, flowing as does a glacier." The rest of Ganymede is covered with a peculiar grooved and ridged surface unlike anything else in the solar system. The grooves and ridges run parallel to each other in some areas; in other places they overlap in a complex braided fashion and twist in geologically mind-bending arabesques. From Voyager 1 photos, planetary scientists believed that Ganymede's terrain could be sorted out into two distinct and reasonable, straightforward geologic eras — an early callistonian era involving the formation of the dark crust and ringed basins, and a later time of groove formation — but Voyager 2's pictures showed some areas with grooved dark terrain. "We're going to have a nice complicated geologic history to unscramble," said one planetary scientist with enthusiasm.

Ganymede's grooved terrain is, for the most part, younger than the dark regions, because there are fewer craters there. This doesn't mean the grooved terrain is young. It's not; it dates back an appreciable fraction of the age of the solar system.

The grooves and ridges are far larger structures than the eagle's-eye view of orbital perspective renders them. The grooves run 5 to 10 miles apart, and in some places have several hundred yards of relief. Where do they come from? They aren't rigid tectonic plates as Earth has, where crust is extruded and consumed, but they appear to be places where sections of dark crust have rubbed and butted against each other, where cracking, sliding, and grinding — powered by forces somehow generated inside the satellite — have faulted and broken the icy crust.

Ganymede's internal structure is also likely to prove fascinating. Crater impacts have excavated material from the crust and spread it around. At first, it looks like all the craters have bright ejecta and bright floors, especially the biggest and youngest. On closer inspection, though, there are craters with dark ejecta and dark floors. And so Ganymede holds a few trump cards: it's more complex than a white inside covered with a thin

JUPITER *continued on page 14*

Ganymede, the largest Galilean satellite, is a mixture of heavily cratered dark and old regions like Callisto's surface, and a light-colored grooved surface that may be much younger. This photo shows a dark circular feature some 2000 miles in diameter crossed by close-spaced bands, much like the impact basin rings seen on Callisto. The small light spots are craters; in the upper left there is a very large crater complex shown in close-up on page 19. The brightish haze in the lower right may be a "snowfall." Ganymede probably has a very thick icy crust.

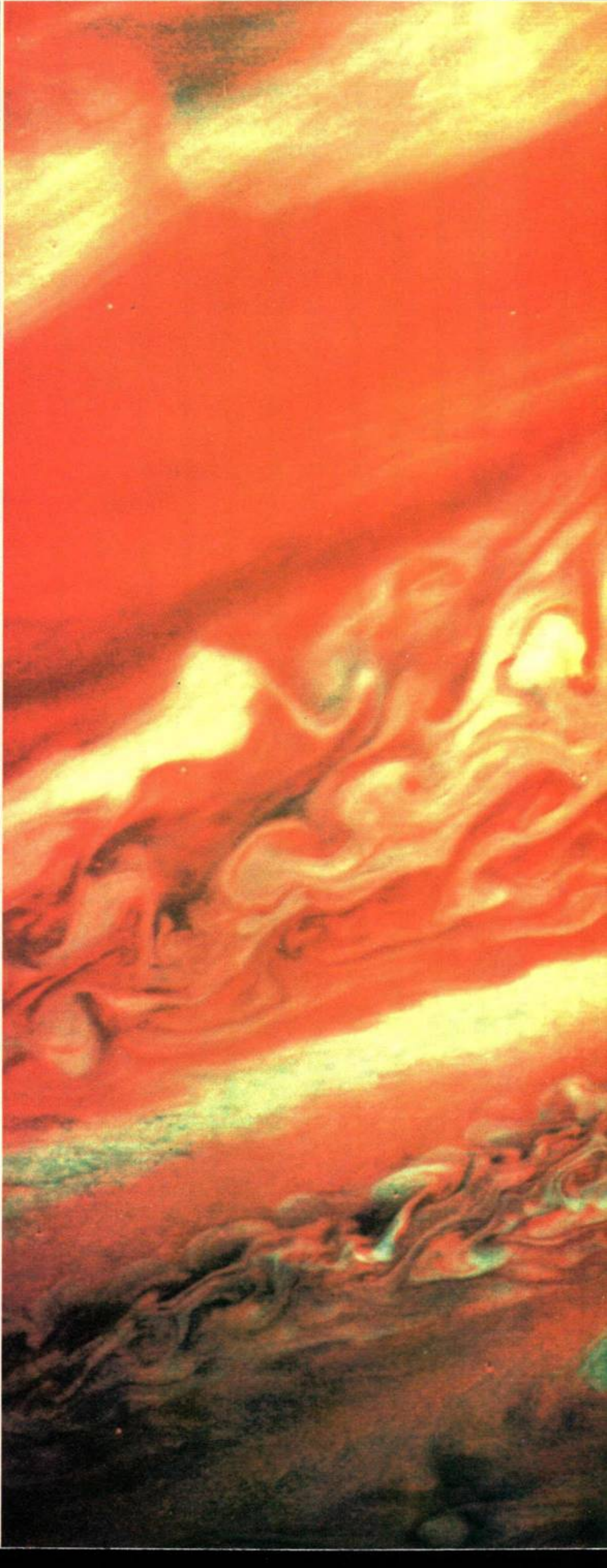
the Great Red Spot

Present for at least the last three centuries, the Great Red Spot is the most famous marking on Jupiter. Why it persists is a mystery. We do know it drifts around the planet in a start-stop fashion and rotates about once every six days, that it is an area of upwelling material and is higher and colder — by about 10 miles and 10 degrees Celsius — than the other clouds of Jupiter. *But why is it red?*

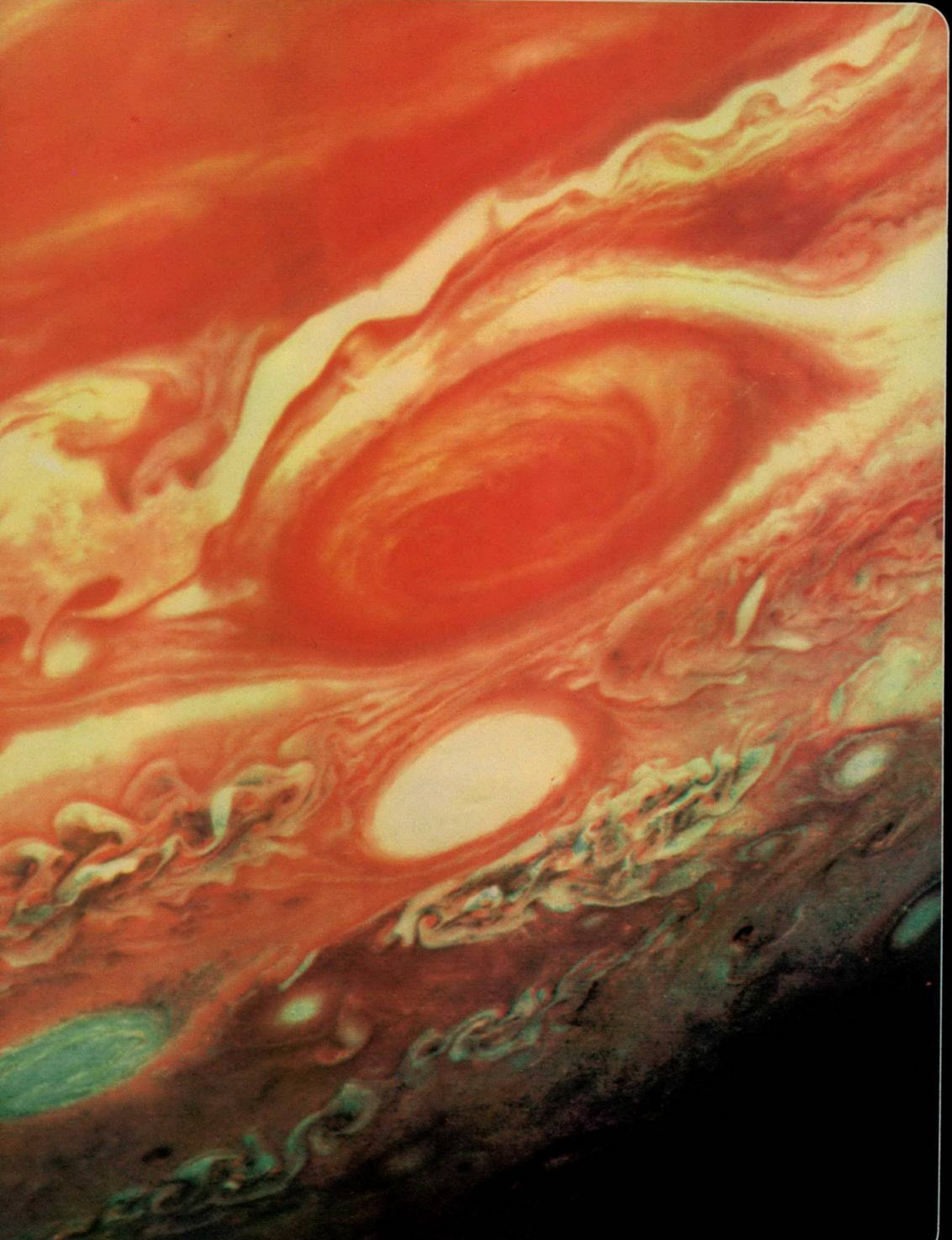
The hydrogen and helium that make up almost all of the jovian atmosphere are transparent. Only when we look deep into a cloudless region or through a great thickness of atmosphere do we see this material at all, and then we see it pale blue because, just as the clear terrestrial atmosphere scatters blue light, so does the clear jovian hydrogen.

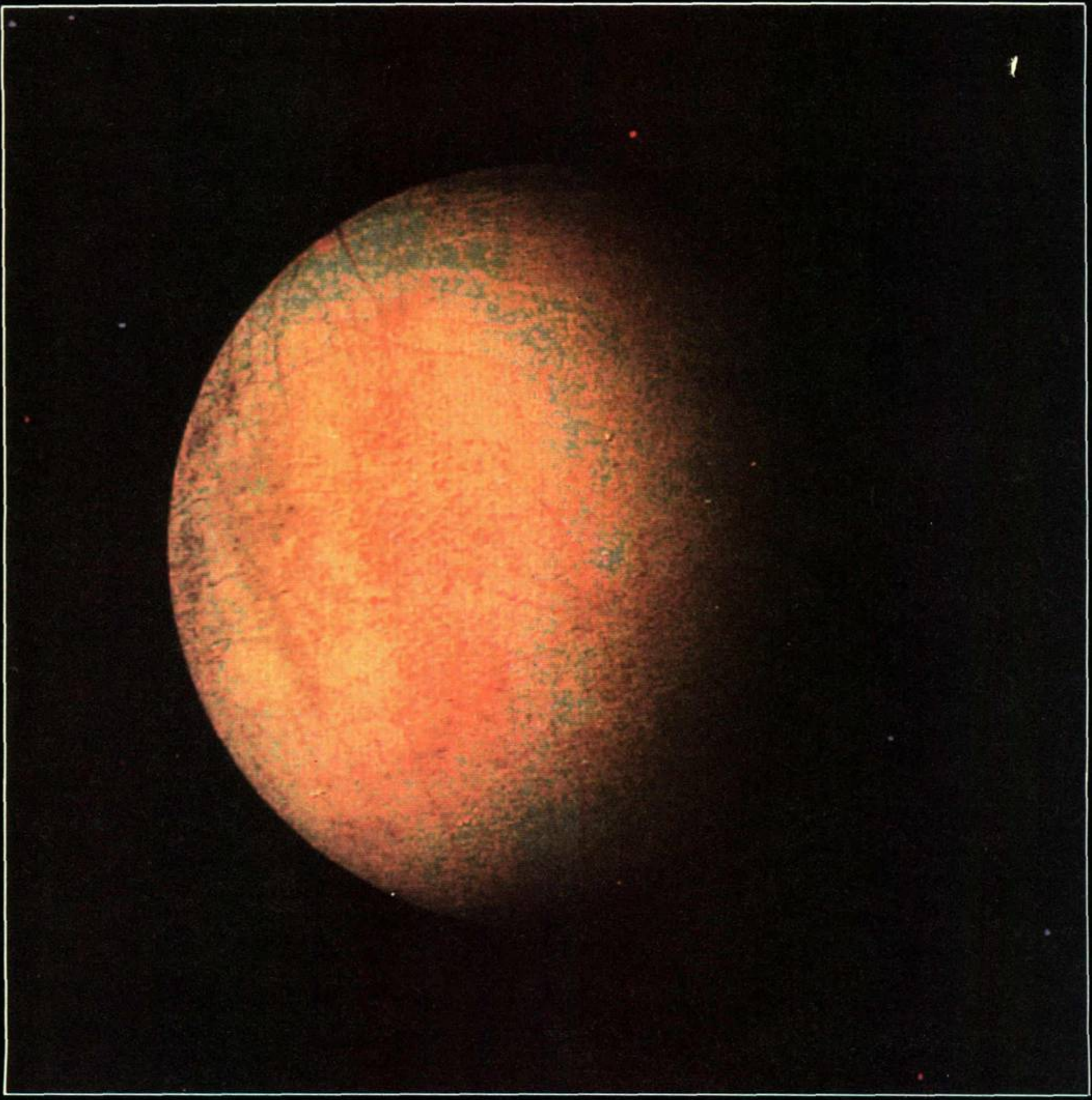
Pure ammonia forms the high white clouds we see in the atmosphere. Ammonia is also the basic ingredient of the lower yellow-orange clouds, but there it is colored by tiny amounts of some other chemical — perhaps certain organic polymers, perhaps some compound of sulfur, nitrogen, and hydrogen. These materials, floating as minute particles in the clouds, are extremely difficult to identify.

But the vivid color of the Red Spot seems to demand a more powerful colorant such as red phosphorus. Exactly how — or where — the jovian atmosphere could form this compound is not known. It might come from deep in the atmosphere (where it could be common) and brought up to the Red Spot, or it may be the unusual physical conditions of the Red Spot itself that transform phosphine gas (PH_3), under the action of sunlight, into red phosphorus (P_4).



This Voyager 2 image shows a bit less than half the diameter of the jovian disk. The disturbed region west (left) of the Red Spot has changed significantly since the Voyager 1 flyby — there are now more small-scale structures and cloud vortices (compare this picture to pictures in the May 1979 issue of ASTRONOMY). A region of white clouds now extends from east (right) of the Red Spot and around its northern boundary, preventing small cloud vortices from circling it, and further east (outside this picture) a major shift in flow pattern has taken place.





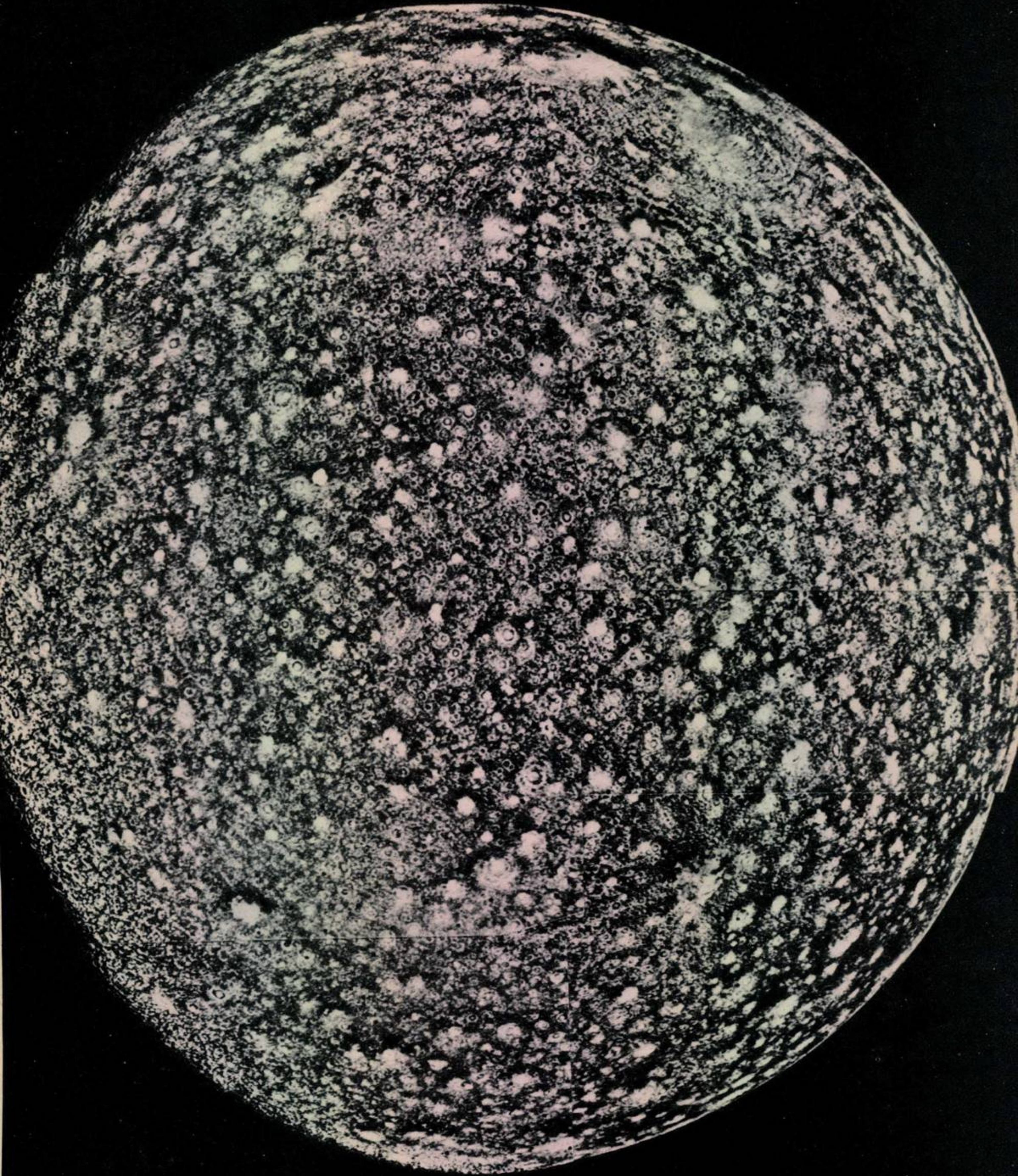
Above: Europa, a golden marble cracked as if hit by a hammer, was recorded by Voyager's cameras the day before closest encounter with the satellite. This picture was contrast-enhanced to bring out differences in surface coloration. The high resolution photograph on pages 6 and 7 shows the region of the limb along the top left. Right: Cratered Callisto looms large in this photomosaic made of computer-processed high-resolution frames. Thousands of overlapping craters make up this ancient surface, though the bright ray craters may be more recent. One of the impact basins is visible at the upper right. Callisto is very smooth owing to its icy composition; no mountains can be seen along the limb.

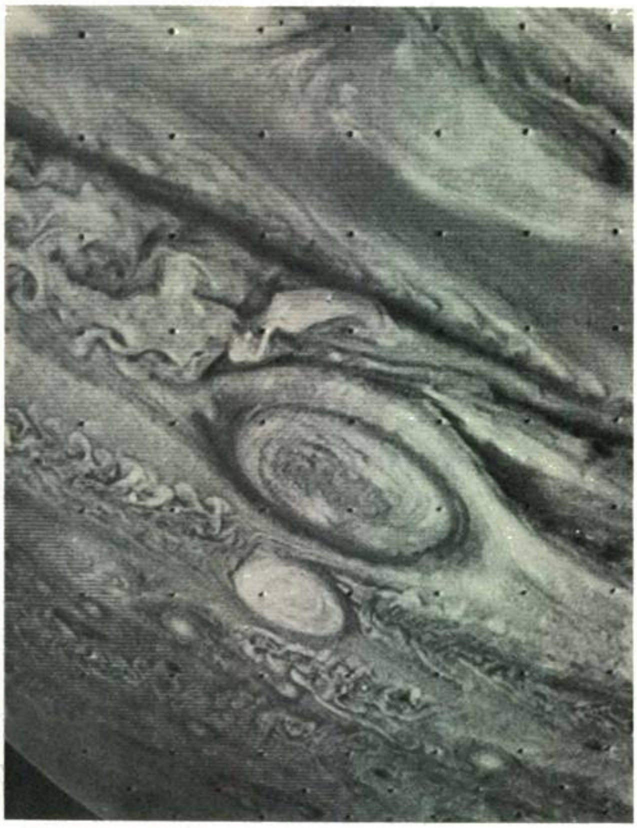
JUPITER *continued from page 10*

dark (dirty?) covering. On a coarse scale, Ganymede probably has an ice crust — perhaps with some rocky contaminants — some 60 to 100 miles thick enclosing a liquid interior.

Europa and Io differ significantly from Ganymede and Callisto: for one, they are almost twice as dense. Unlike the outer two moons, which may consist largely of liquid water and ice with rocky bits of contamination tossed in, Io and Europa are primarily rocky bodies with densities bracketing that of Earth's Moon. Europa is the less dense of the pair; it appears to be rich in lightweight ices, and may, in fact, be covered with a planetwide water-ice glacier. Europa, in order to account for its density, must have a silicate rock core under the glacial layers.

Io, at least in its outer layers, is totally devoid of water. The volcanic plumes show no trace of water or carbon dioxide, only the heavy molecules of sulfur dioxide and elemental sulfur spray from its volcanic vents. Planetologists are busy asking themselves how Io could have gotten rid of its water (if indeed it had any at the time of formation). The sequence through the jovian satellite system —





from dry Io, to damp Europa, to watery (or icy) Ganymede and Callisto — is too tempting a clue: it must clearly have importance in the cosmogony of the jovian system.

Europa was not seen in close-up by Voyager 1; only the large-scale pattern of cracks was known. Voyager 2 was its mission of discovery. Europa's cracks turned out to be essentially flat, somewhat diffuse (that is, fuzzy-edged) dark stripes some 10 to 25 miles wide, running thousands of miles around the planet. The cracks are a good deal more concentrated in some areas, and open into wide bays in others. Planetologists quickly proposed a number of models — such as a surface-freezing model, which postulates that the surface froze first and as the deeper layers froze, the surface was cracked.

The darker regions on the planet turned out to be almost as flat as the extensive whitish cracked areas, and in fact the only significant features with any surface relief at all turned out to be the bright stripes. Even these features are several miles wide and offer elevations less than 50 yards. Europa is very much flatter than a billiard ball.

Furthermore, Europa is remarkably free of craters, though not so free as Io, which has none at all. This means, essentially, that Europa must still be active today. Scientists are now fairly certain that Io is heated by tidal friction: if Europa is heated by tidal friction also, its icy crust may become softened. From the surface detail, we know the surface is plastic enough that craters are erased and mountains flatten out.

If Europa represents our highest state of ignorance, then Io is the Galilean satellite we know most about. Io, closest to Jupiter, is strongly heated by tidal friction, enough so that at least eight giant volcanic plumes spout from its surface. Io is obliging: while we can observe only the bumps and colors of the other three satellites and measure their overall densities, Io spews out clues about its internal workings.

Io's surface is a hell. Virtually every type of volcanism seen on Earth has been seen on Io: there are the violent eruptive volcanos, of course, but there are also thin stringy flows of lava, broad lobate flows, ashy flows, and calderas, lava lakes, and lava issuing from fissures. "Io displays," as a volcanologist put it, "a broad range of eruptive styles."

Io's lava exits the volcanic vent as a frothing mixture of liquid and gas, but as it rises, it cools into fine dust, ash, perhaps even larger lumps, and falls — in a graceful ballistic trajectory — back to the surface. Igneous materials build up around the base of the vent, and a huge apron of debris spreads across thousands of square miles.

Averaged over the whole of Io, the buildup amounts to 1/10 to 1 millimeter per year. This may not sound like much, but if volcanism has been continuous for a billion years, between 60 and 600 miles of surface material will have been recycled. Over the 4½-billion-year life of the solar system, it's possible that the entire bulk of Io could have been recycled through its volcanos. No wonder the primitive surface of Io is no longer present: this is a planet that could have turned itself entirely inside out!

But it probably isn't that simple — it's far more likely that Io has a core of molten rock wrapped in a thin, solid, outer mantle of silicate rock perhaps 12 miles thick and complexly layered. Io, being close to Jupiter, experiences large tides that bend the crust of the planet in and out several hundred feet with every orbital revolution. The bending heats the crust, melts rock and sulfur, and drives the volcanos. All the Voyager scientists agree on these basic features. Beyond this, they differ.

Some propose that above the silicate crust is an ocean of liquid sulfur, and floating on it a mixture of solid sulfur and liquid sulfur dioxide. The icing on the cake is another layer of pure solid sulfur perhaps 1000 feet thick. In this picture, volcanos literally explode through weak spots in the outer crust driven by the pressure of liquid sulfur dioxide boiling into a gas and carrying with it sulfur from the interior. The crust is built up on the outside and remelted on the inside — the same material recycling through, again and again.

In some places on Io, the outer crust may have been broken, and instead of the violent jet, the molten sulfur may flow out in a relatively quiet fashion. There is no reason to think that all of Io has the same underlying structure — so several variations on the basic models may serve to explain the variety of different surfaces seen on the planet.

On the other hand, perhaps Io's solid silicate crust is simply sulfur-rich, the molten rock from the interior similarly sulfur-rich, the volcanos powered by boiling sulfur, and the surface covered with a thin layer of colorful frozen sulfur and sulfur compounds.

A basic question remains: Where did all the sulfur come from? From the infrared spectrometer data, scientists found that Io's volcanic plumes were completely water-free, and furthermore, free of carbon dioxide and other light gases. Yet the next moon out (Europa) has a thick mantle of water. The question on everybody's minds is: Did Io get an unusual amount of sulfur or did some process, presumably volcanic, selectively remove other volatile materials and leave sulfur as a residue?

Calculations made by Voyager planetologists show that it isn't, in fact, necessary to give Io an enormous dose of sulfur when it was formed — it's quite enough to remove the water, methane, and carbon dioxide from about one-fifth of Io's rocks to leave the sulfur the Voyagers found. Driven by continuous tidal heating, Io's volcanos could indeed have boiled off the lighter gases.

Io and Jupiter are not alone in space. Enfolding and enveloping the massive bodies of the solar system are tenuous, invisible magnetic and electric fields, swarms of atomic particles, and electromagnetic radiation — light, radio, infrared, and ultraviolet. The Voyagers probed this invisible environment also.

What happens to the material that's ejected from Io's volcanos has no match elsewhere in the solar system. It's a story of complex interactions between Jupiter's magnetic field — the most powerful in the solar system — the system's most volcanic body (Io), and a stream of atomic particles from the Sun (the solar wind).

The story begins at Io. There, driven by heat released in the solid outer crust by the powerful tidal influence of Jupiter, molten silicate rock, sulfur, and sulfur dioxide spurt hundreds of miles from Io's surface. Rock and sulfur fall back to the surface, but the sulfur dioxide remains a gas, an Io atmosphere. It isn't much of an atmosphere, in total perhaps one ten-millionth what Earth has at its surface, but it was readily detected by the infrared instruments aboard both Voyagers.

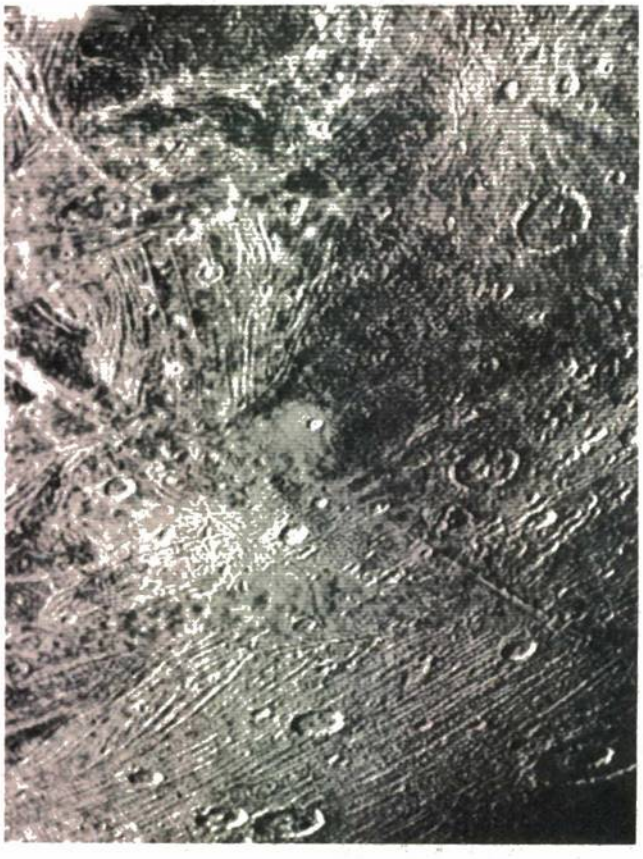
Io orbits Jupiter once every 40 hours, but mighty Jupiter spins on its axis about once every 10 hours, dragging its magnetic field with it. Embedded in the magnetic field is a plasma — a hot mixture of ions (atoms stripped of their electrons) and electrons. Because a plasma is made up of charged particles (which cannot move across a magnetic field without doing work), the plasma is trapped in the magnetic field.

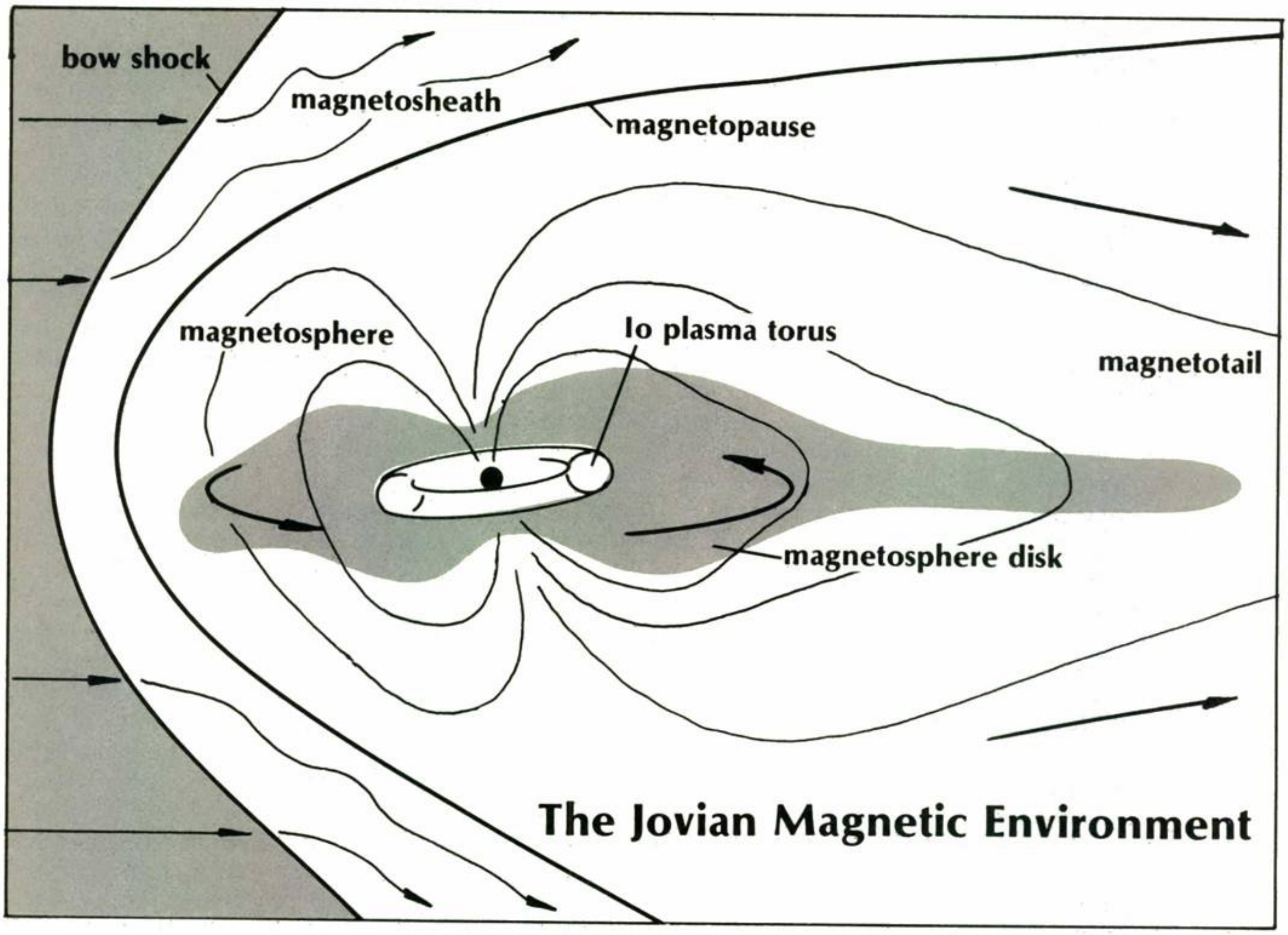
At Io's distance, the magnetic field is sweeping around Jupiter far faster than Io orbits it, so some of the trapped electrons come smashing down into Io's atmosphere, knocking electrons off gas molecules, and converting their atoms to ions. Atoms are not affected much by a magnetic field, because they're electrically neutral, but ions are. Once ionized, Io's atmospheric gas is suddenly influenced by the powerful magnetic field spinning by, and whipped off into space. Every second Io loses 10^{28} to 10^{29} ions — mainly sulfur and oxygen ions — to this process, or about two tons of sulfur dioxide gas.

It takes an enormous amount of energy to rip so much material off the surface of this little moon and send it spinning into space — much more energy, in fact, than powers all of the Io volcanos. The driving energy comes from Jupiter's rotation. Both Jupiter and the magnetic field are retarded (slowed) by pulling so much material off into space. Beyond Io, the plasma no longer spins with Jupiter, but instead drags behind. Jupiter starts to lose his grip on the plasma.

Once in space, the sulphur and oxygen ions spread out into a complete ring surrounding Jupiter. Unable to cross the magnetic field lines easily, they spiral around them, oscillating above and below the plane of Io's orbit. This huge ring, rotating with Jupiter's magnetic field once every ten hours, is called the Io *plasma torus*.

When Pioneer 10 and 11 flew past Jupiter in 1973 and 1974, they did not detect a plasma torus, although both probes had instruments capable of doing so. They did detect a cloud of hydrogen around Io. It is clear from a comparison of the data





obtained then and now, that something has changed.

The torus is energized by the jovian magnetic field and fueled by the gas from Io's volcanos. It may seem difficult to imagine that all the volcanos on Io were turned off when the Pioneers flew by, yet appeared so active at the Voyager flybys only 5½ years later, yet the volcanos are the only real candidates for change. It is more difficult to believe that the jovian magnetic field could have changed so drastically that if the gas were available on Io, it wouldn't be converted into a plasma torus.

It's also unlikely that the Pioneer spacecraft simply failed to detect the torus, because at certain sulfur-ion wavelengths, the torus emits about one trillion watts of ultraviolet radiation, which the scientists feel could not have been missed.

The ultraviolet radiation from the torus consumes so much energy that the whole torus would run down and turn off in a matter of days if fresh particles — and energy — were not continually pumped into it. The torus, then, is no permanent feature of Jupiter, but an extremely dynamic feature — here today, gone tomorrow — at the whim of the Io volcanos.

The torus powers a number of other jovian phenomena: the belts of aurorae discovered by Voyager 1, for example. The magnetic field lines that pass through the torus enter the jovian atmosphere along a large oval region circling both poles; some electrons escape the torus and spiral down into the upper jovian atmosphere, exciting atoms to glow as an aurora.

An oxygen or sulfur atom, ionized and stripped away from Io may remain trapped in the torus for a day or two, spiraling along the field lines, bouncing from north to south and back again, colliding with electrons and emitting energy as ultraviolet light. But sooner or later, it encounters irregularities in the magnetic field and begins to diffuse out of the torus.

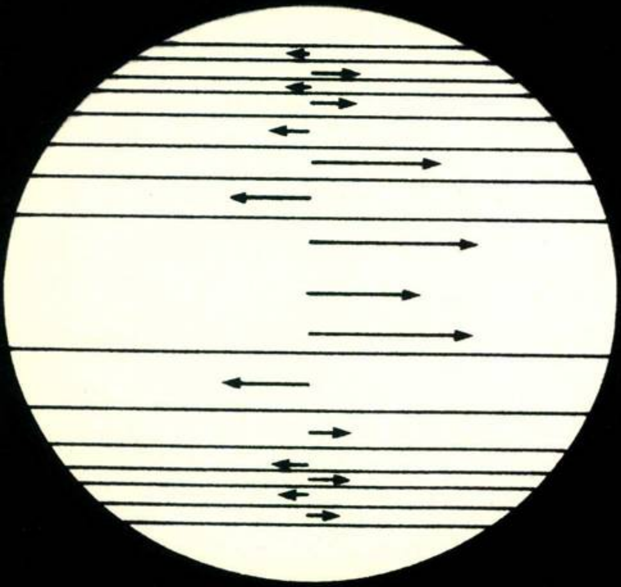
It may move inward to an extremely high-energy belt of radiation inside Io's orbit, where particles are accelerated to speeds approaching one tenth that of light. This region, called the trapped radiation belt, closely resembles the Earth's van Allen radiation belts.

The particles may also move outward into Jupiter's extended magnetospheric disk, an enormous tenuous structure containing only a few

JUPITER *continued on page 23*

The surface of Ganymede is rich and complex. The region of this close-up picture, showing bright-rayed craters at the top, can be found on the picture of all of Ganymede on page 11. Bright crater rays overlie older, light-toned, grooved terrain that may result from motion between older crustal "plates." Grooved terrain is younger than the darker ungrooved regions that resemble the crust of Callisto.

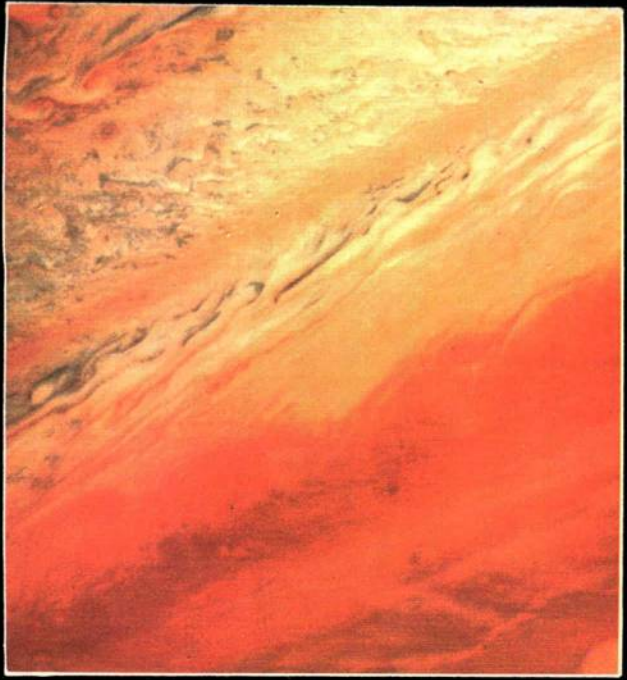
The Jovian



Jupiter's clouds had long seemed capricious to Earth-bound observers — spots, ovals, bands, belts, and festoons seemed to come, go, or linger for decades with no apparent order. The high resolution pictures from Voyager 1 and the time-lapse movies made from them gave an impression of intractable chaos.

Jupiter is a planet of weather, weather on a grand scale totally unknown to planet Earth; as, indeed, many of the larger storms and swirls are bigger than our entire planet. And yet...in that chaos Voyager investigators found order. The bands of clouds have sometimes persisted for centuries, individual spots for decades, and the Great Red Spot itself has been there for over 300 years. "We are now beginning to see the order underneath," said Voyager scientist Andrew Ingersoll, "but it's hard to understand how such large-scale fluids can be so orderly." Measurements of the velocities of small spots in the jovian atmosphere show a regular pattern of alternate east and west wind velocities. "We've found every current ever seen in the last 75 years of Earth-based measurements in one ten-hour Voyager sequence," said Ingersoll; "these flows persist even when the belts and zones change."

Jupiter's deeper layers must be more important and the cloud patterns less important than had been previously thought. What powers it all? Deep zonal flow persists from inertia, but the energy to drive it comes from deep inside Jupiter itself.



Left: One of the long dark clouds observed in the jovian north equatorial belt. A high white cloud can be seen overlying the darker cloud, providing an indication of the height relations between the different kinds of clouds. Right: Spanning about one-fourth the jovian disk, this close-up shows the north temperate jet, a thin brownish band running from left to upper right, where the wind speed is approximately 330 miles per hour. The wispy clouds of the north equatorial belt appear in various shades of brown. The small blue areas are holes where we can see to depths of perhaps 40 miles — they are blue for the same reasons the clear daytime sky on Earth is blue.

Clouds

JUPITER

continued from page 18

million tons of material, yet over two million miles across. Held in the grip of the jovian magnetic field (which is tipped to Jupiter's spin axis by about 10°) the disk spins and wobbles up and down in a drunken flopping motion. The particles move farther and farther out and finally, two to three weeks after exiting a volcanic vent on the surface of Io, escape Jupiter's influence by flowing down the magnetotail and off into deep space.

Clearly Io plays a vital role in Jupiter's electromagnetic and particle environment. The other major influence is the Sun, or rather the stream of high-velocity atomic particles (mostly protons) flowing from the Sun, known as the solar wind. When the solar wind crosses Earth's orbit, its particles are traveling at several million miles per hour; by the time they've reached Jupiter, they've slowed to about one million miles per hour.

If Jupiter's magnetic field were alone in space, it would expand symmetrically in all directions, infinitely. But under the impact of the charged particles in the solar wind, the magnetic field is warped, bent back, folded, and turned upon itself, so that it spreads out in space away from the Sun. The position of the magnetic field depends on an uneasy balance between the pressure of the solar wind, the resiliance of the magnetic field, and the pressure of particles inside the magnetic field. The solar wind's first encounter with the jovian magnetic field comes suddenly; there is no buildup of pressure, just the sudden violent shock of entering a strong magnetic regime and being twisted and violently slowed. The meeting place is called the bow shock. Inside the bow shock the solar wind is deflected and flows around Jupiter, through the twisted magnetic field lines and irregular flows of plasma. The solar wind doesn't penetrate inside the jovian inner sanctum, the magnetosphere. Inside the magnetopause lies the jovian realm.

When the Voyager spacecraft encountered Jupiter, they met the bow shock not once, but many times, because the zone of collision, perhaps 2 million miles ahead of Jupiter, moves back and forth depending on the vagaries of the solar wind. The charged particle detectors on the spacecraft observed the standard mix of solar wind ions until, abruptly, at the magnetopause, the spacecraft entered the magnetosphere. Suddenly the instruments detected not hydrogen, carbon, calcium, and iron, but the sulfurous exhalations of Io's volcanos whirling in the jovian magnetic field. Then the scientists knew they'd reached Jupiter.

White ovals are large rotating flows with long lives, similar, except for color, to the Red Spot. The white oval shown (recorded by Voyager 2) is very similar to the white oval seen near the Red Spot during the Voyager 1 flyby, but it's not the same one: that one has drifted about one-eighth of the way around Jupiter (to the right) during the intervening four months. Note that clouds between the white oval and the Red Spot are "squeezed" as they flow between the two.

For each picture shown on these pages, this table gives the date taken and the distance between the Voyager 2 spacecraft and the object. The picture's number is NASA's designation and specifies the image uniquely in their files.

Page	Date	Range (miles)	Picture #
4-5	July 7	677,000	P-21748C
6	July 9	150,000	P-21760C
7	July 9	150,000	P-21764C
8	July 10	750,000	P-21773
11	July 7	1,200,000	P-21762C
12-13	July 3	3,720,000	P-21742C
14	July 8	1,200,000	P-21752C
15	July 7	245,000	P-21746
19	July 8	120,000	P-21762C
20	July 6	2,000,000	P-21753C
21	July 6	2,200,000	P-21747C
22	July 5	2,600,000	P-21737C

Richard Berry, ASTRONOMY's Editor, covered the Voyager 2 flyby during seven exciting days and nights in the JPL pressroom. JPL manages and controls Project Voyager for NASA's Office of Space Science. All photographs in this article listed above are courtesy of JPL and NASA; other photographs were taken directly from the pressroom TV monitors.

Postlude

The day after closest approach, Voyager swung its cameras back toward Jupiter to photograph lightning and aurora on the night side. Small motors whined, automatic sequencers buzzed, filters clicked into place, shutters opened, cameras recorded, digitized, and beamed a stream of data back toward Earth. Fifty-two minutes later, a picture appeared on the monitors, then more pictures, showing the great sweep of the jovian limb, and — wonderfully — a thin but bright jovian ring arcing around the planet.

Jupiter had been holding one final surprise: the ring, faint from the front side, glowed brilliantly from behind. The brightest part of the ring measured some 4,000 miles wide, but the glow inside the ring showed it might extend all the way to the surface of the planet.

It was what scientists call "strongly forward-scattering," meaning that its particles tend to bend a beam of light a little to the side, rather than bounce it back to the source of the light. Droplets in terrestrial fog behave this way.

It also means that the ring is made of fine particles, posing severe difficulties for planetary scientists. A ring made of fine material is removed very quickly by a number of natural processes; no ring where Jupiter's ring is could last more than a few million years. And yet — there it was.

Is the ring always there, or is it the result of some one-time event that mankind is lucky enough to have seen? Might the ring be renewed continuously, perhaps, by a supply of material from (where else) Io? We are just learning these things, and that is possibly the most wonderful thing of all.

ASTRONOMY forum

Voyager — Why It's Important

This speech was delivered before the scientists and press assembled in the Von Kármán Auditorium at the Jet Propulsion Laboratory on Monday, July 9, about an hour after Voyager 2 made its closest approach to Jupiter.

It is unfortunate, I think, that we live in a society where everything, apparently of necessity, is billed in very large terms. So events are termed unique, and when we balk at that, we say they're "almost unique" (which is a strange combination of words). If they're not unique, they're stupendous, one-of-a-kind, never-before-found, never-before-seen, and so forth and so on. The unfortunate thing is that when we confront a truly spectacular event, we don't know it. Or, at best, we're a little embarrassed to admit it. The simple fact is that we have been witnessing, first in March and now in July, a truly revolutionary journey of exploration. I would submit that you know it, but you're a little embarrassed to say it.

We have gone beyond the familiar part of the solar system; we've gone to objects that are so exotic that their very existence, at least as far as I'm concerned, was something I'd accepted intellectually but didn't really accept in an immediate sense. I was reminded of that when I saw one of the first Voyager 1 pictures, and there was Jupiter with (these) little marble-like satellites in front of it, and I said, "I just can't believe it," and one of my friends said, "What did you expect them to look like?". Well, the laws of physics say that at that particular size, they have to be spherical, which is of course true, but the point was that I just didn't accept this as a reality. And now, of course, all that has changed.

In my own mind, I've tried to come up with some sort of comparison which somehow makes it more meaningful for me, and the one which I often fall back on, is to compare this later part of the 20th century with the 15th and 16th centuries — the time during which the oceans of the Earth were first explored. You will recall that sailing ships first edged their way along the shores of Europe, then they hopscotched their way around Africa, and finally they struck out across the open ocean. They headed for lands that were so remote, countries so extraordinary, that the reports of the returning explorers were even more incredible than the fictions they replaced. Today we're replacing these imaginary "images" of Jupiter and its satellites with actual physical reports.

So we're starting out now — and I think we are starting out our space program on a new stage of exploration — on our own long journey beyond the inner solar system to distant lands. The Pioneer 11 craft is now approaching Saturn, to swing by, as will Voyagers 1 and 2; the Voyager 2 encounter with Uranus will take place almost eight years after launch, and Galileo will orbit Jupiter and drop a probe in its atmosphere. And beyond that, we look forward to other missions: a spacecraft that'll orbit Venus and send radar signals down through the clouds to acquire pictures of the surface which might have extraordinary implications, comparatively, for Earth. We look forward to another spacecraft that will fly by comet Halley and go on to fly beside another comet, comet Tempel, as it arcs its way around the Sun. We look forward to a gamma-ray astronomy mission, a spacecraft in Earth orbit that will look out into our Galaxy, beyond our Galaxy, searching for bursts of energy that may give us very important clues about the very generation of the elements.

I would be less than candid if I suggested that all this will happen simply because I say that it will happen. Every one of the missions just described to you, with the exception of Voyager of course (which has been described as a mission with no problems), faces very serious technical problems, but even more serious, they face very severe financial problems. Nonetheless, I think it's all going to happen. I decided to leave Brown University for a few years — I teach there; I had a very happy and predictable future in front of me, but I made the free decision to come down to Washington and participate in what is frankly a very difficult time. I think, however, that it is a particularly difficult summer, even a particularly difficult week with Skylab poised above us, but we will survive and the exploration of space will proceed pretty much as I have just described it.

Finally, I point out to you something we're again a little bit embarrassed to own up to. We never like to think, or rather it's statistically unlikely, that we're at a turning point in history. But if you look back at history books, such events clearly are read into the record. And so you dutifully learn about the Reformation, about the Renaissance, about the American Revolution, and many events like them. And I submit to you that when the history books are written a hundred years from now, two hundred years from now, the historians, in a similar way, are going to cite this particular period of exploration as a turning point in our cultural, scientific, and intellectual development. I really believe this, and in personal conversation I have found any number of people who say they also believe, that a society which turns its back on exploration, on intellectual exploration, cultural exploration, physical exploration, is a society, a civilization, that is very close to a period of decline. And I don't think that we in this country with our particular pioneering spirit, are going to settle for a period of decline.

Timothy Mutch
Associate Administator
for Space Science
NASA

Dr. Mutch is the former head of the Viking Lander Imaging Team.

The Discovery of Jupiter's Ring

Dr. Tobias Owen of the State University of New York at Stony Brook was a member of the team which discovered the ring of Jupiter during the Voyager 1 flyby last March. He was interviewed by ASTRONOMY immediately after the press conference at which the discovery was announced. Here is a part of that interview:

ASTRONOMY: How was the ring actually discovered? Was it just seen by a number of people at once on the monitors as it came up, or did it require some enhancement of the image?

Owen: No, well, I can show you the

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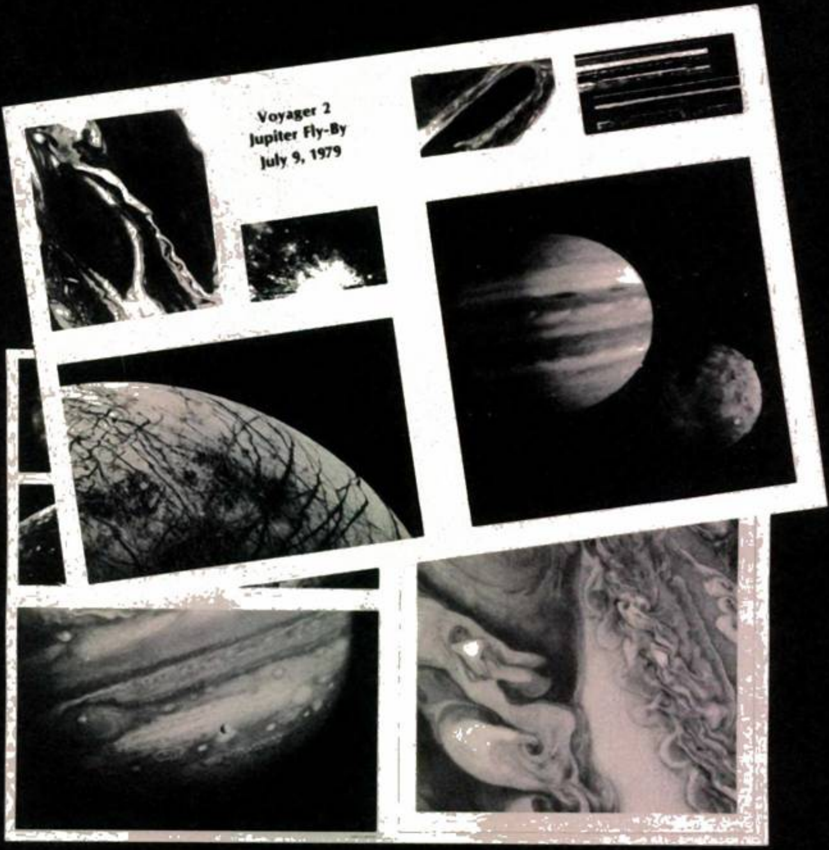

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original discovery picture, so to speak. It's just a crummy little polaroid that was taken off the screen. It was actually taken by engineers who were monitoring the spacecraft data, and they brought this in. We could see that we had something, but we didn't know what it was.

ASTRONOMY: Were you puzzled by the "wiggle" in the star images?

Owen: No, we expected that that would happen, because of spacecraft motion. We knew the craft wouldn't be exactly quiet — it never is. But then we had to go back and unravel it, and figure out how we could relate it to the real motions of the spacecraft.

ASTRONOMY: Was there an immediate reaction to this picture, that "we really have *got* something here"?

Owen: Yes, but some people thought it might be scattered light in the camera; some people thought it might be a nearby satellite that was moving through the field of view; and it wasn't until we got the thing you've seen up on the screen [the high resolution image] that we could see that *these* six things correlated with *those* six things. Then we knew we were in good shape.

ASTRONOMY: Are there any plans to take more photos of that region now?

Owen: Oh, yes! On the next spacecraft.

ASTRONOMY: On the next, but not on this one?

Owen: Well, we're taking pictures of that region right now, but we don't see anything because we're out of the plane [of the ring]. We're four degrees out, and the ring is so thin that we're just looking right through it.

ASTRONOMY: And you feel sure there wouldn't be any chance of imaging it?

Owen: Afraid not. It's too thin, too faint.

ASTRONOMY: How much doubt was there on the team about looking for a ring?

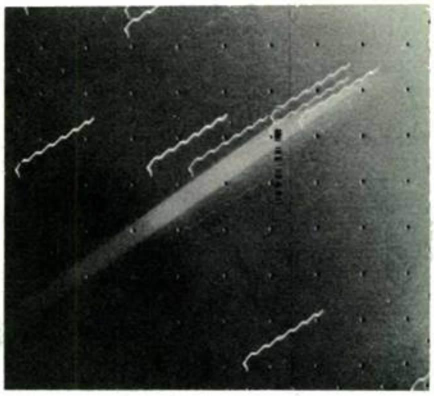
Owen: Well, yes, it was a chance. Sure, it was a risk, and some people felt that it was so much of a risk — that it was so unlikely — that we shouldn't take the time to do it; we should be doing other observations. There wasn't just competition in our team, which finally did agree to do it. Our team has observations it wants to do when other teams were doing other things, so we had to convince them to do it too.

ASTRONOMY: Was the time spent in equatorial passage so short that you only had time for one shot?

Owen: That's right.

ASTRONOMY: Even if the others had gone along, you still couldn't have taken more than one shot?

Owen: Well, if we'd had all the time we wanted, we could have done more things.



ASTRONOMY: You did have time for a full eleven minute exposure.

Owen: That was good, but we used it all up. Now we know we can use shorter exposures, so in that time we can take several exposures.

ASTRONOMY: What about Voyager 2?

Owen: It turns out we have the time. It's our time.

ASTRONOMY: If you're looking at the edge of the ring, then you will be looking through a greater thickness of material, and as you move in toward the planet there should be a gradient in the ring's brightness?

Owen: That's right.

ASTRONOMY: Does that give you any indication of how wide the ring might be?

Owen: It could. It could. Depending ...yes.

ASTRONOMY: But of course this image shows such a small region.

Owen: That's right.

ASTRONOMY: Can you set a lower limit, perhaps?

Owen: Well, I think from this view we won't be able to do too much. But with the next spacecraft [Voyager 2], our intention is to get a series of images going right in, and then we can look for the kind of gradient you're talking about.

ASTRONOMY: On this image it doesn't look like there's any gradient at all.

Owen: Sure doesn't. And that would say that it has to be at least 9000 kilometers wide. That's the length of those trails.

ASTRONOMY: What can you say at this time about the significance of this discovery?

Owen: You've got another planet with a ring system, basically. In addition to everything else it has going for it, Jupiter also has rings, and you now really want to know: Does Neptune have a ring system as well?

ASTRONOMY: As the current chairman for the international group on nomenclature, what can you say about the prospects for naming the features that have been discovered?

Owen: What we've already agreed to is that we're going to name the features on the satellites after characters and places in myths and folktales of all the different cultures. So we've got a huge name bank, and now we want to try to work out some sort of rational scheme so we have a set of names for Io that is completely different from the set for Callisto, say. So [for example] we might name Io features after African and Polynesian mythical figures, and the Callisto after the Norse myths.

ASTRONOMY: Does this commission have final authority, or will its decisions have to be confirmed at the IAU [International Astronomical Union] meeting in August?

Owen: The latter. We make recommendations, but in practice they always approve them. We haven't done anything outrageous yet!

ASTRONOMY: Another thing I'd like to ask is awfully speculative. Has there been any talk among the scientists about a greater desirability for a more sophisticated mission to Jupiter because of the results of this one? Something that would involve landings, for example, landers on the various satellites?

Owen: There has been talk about that for a long time, and nothing we've seen so far would dampen it, I'm sure. There already is a mission, as you probably know [Galileo], to put a probe into the atmosphere [of Jupiter], which is going to be very exciting. Satellite landers have been discussed, and geologists are very excited about the possibility. Even satellite orbiters have been talked about.

ASTRONOMY: I imagine there would be a feeling that an even better case could be made now for landers because of this, because of the surprises that have come back.

Owen: That's right, that's right.

ASTRONOMY: The problem, of course, is budgetary.

Owen: Yes indeed, it's a big problem. It's important for the country's leaders to get behind this kind of thing. Perhaps with a strong challenge to [President] Carter from [Governor] Brown [of California, a strong advocate for a vigorous space program] — then Carter will respond by opening up the space program.

ASTRONOMY: Thank you, Dr. Owen.

Lusty Legends

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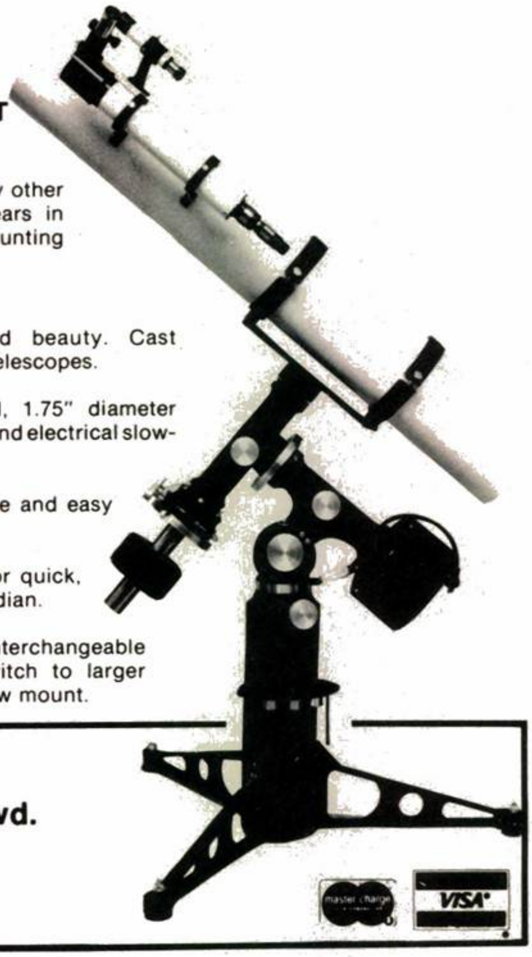

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worlds quite different from what many scientists had anticipated. But how many know of the equally colorful and imaginative Greco-Roman mythologies behind the names of the giant planet and its four large attendant moons: Io, Europa, Callisto and Ganymede?

Readily visible to night sky watchers throughout the ages, the planet Jupiter takes its name from the ancient god of light who resided on Mount Olympus. Romans considered this chief-god Jupiter (son of the Titan Saturn) the father of day and weather.

Although history credits Galileo Galilei with first sighting Jupiter's four largest moons in 1610, Bavarian astronomer Simon Mayer probably observed them about ten days before the famous Italian. However, Mayer did not recognize the significance of these satellites and failed to reveal his discovery until after Galileo's findings were published. Nevertheless, all the Galilean satellites bear names proposed by Mayer, those of Jupiter's lovers in mythological legends.

Ancient myths portray Jupiter, Roman counterpart to the Greek god Zeus, as a patriarchal, masculine, and stormy king of the gods, a title befitting the massive, turbulent planet. Art from this period often shows the powerful ruler accompanied by an eagle, symbol of Jupiter's strength and authority, and hurling lightning bolts, his chief weapon.

Known for his righteousness and omnipotence, Jupiter also acquired a lusty reputation for reckless love affairs. Indeed, the amorous god spent much of his time pursuing beautiful mortals, such as Io, Europa, Callisto, Ganymede, and others.

But how did Jupiter, god of law and morals, come by such a notorious reputation?

According to Professor Carl Ruck of Boston University, ancient rival cultures worshipped different deities. As principal god of the dominant Greco-Romans, Jupiter (Zeus) attempted to assimilate all the previous divinities. Even though these deities already existed, said Ruck, in some instances they were reborn in new myths as Jupiter's children, while in others they became his wives. It happened over and over again in these legends.

The story connected with Io recounts Jupiter's passion for a lovely nymph. One afternoon Jupiter noticed Io, daughter of the river god Inachus, returning from her father's stream. Charmed by the girl's disarming beauty, the Olympian surrounded the Earth with a dark cloud in order to ravish Io without being seen by his legitimate wife, the vindictive Juno (Hera), queen of the gods.

Suspicious of both the cloud and her husband's absence, Juno descended to Earth and determinedly brushed away Jupiter's deceptive cloak. Knowing well Juno's jealous nature, Jupiter anticipated his spouse's move and turned poor Io into a beautiful white heifer. When Juno questioned her mate about the young cow, Jupiter explained that it had sprung from the Earth. Unconvinced, Juno asked for the animal as a gift. What could Jupiter do? He realized to deny this request would arouse further suspicion, so the mighty god reluctantly consented.

Juno next sent a 100-eyed monster, Argus, to guard her heifer. Since Argus never slept with more than two eyes closed, he kept Io under constant watch.

About this time, Inachus became worried and began to search for his missing daughter. Unable to speak, Io could only inform the river god of her sad fate by writing Io in the dust with her hoof. Inachus immediately realized what had happened and, overcome by grief, threw his arms around Io's neck and wept.

Jupiter took pity on the hapless girl and sent his messenger Mercury (Hermes) to kill the ever-watchful monster. Armed with a sleep-producing wand and dressed as a shepherd, Mercury slowly shut Argus' eyes by playing soothing music on his pipes and, as soon as the horrible monster fell asleep, Jupiter's messenger cut off its head with a mighty blow of his sword. Juno took the 100 eyes and placed them on the tail of her favorite bird, the peacock.

Still vengeful, Juno sent a gadfly to torment Io. The beleaguered girl fled its relentless pursuit by swimming across the Ionian Sea, which derived its name from her. She wandered long over mountains and vast plains until finally, when Io reached Egypt, Jupiter interceded for her. The mighty god promised Juno he would never again pay any attention to Io. Juno agreed and Jupiter restored the girl to her original form.

Europa, an extremely cold, ice-covered satellite about the size of Earth's Moon, also has an amorous adventure tied to its name. Jupiter fell madly in love with beautiful Europa, daughter of the Phoenician king, and desired her. When the god saw this innocent girl and her friends playing along the seashore one morning, he sent mischievous Mercury to drive the king's cattle down near this spot. Putting aside his lightning and royal scepter, Jupiter cleverly transformed himself into a majestic white bull and mingled among the herd.

Although initially frightened by this magnificent animal, Europa soon lost all fear. She caressed the bull and unwittingly climbed upon its back. Seeing his chance, Jupiter jumped into the sea and whisked Europa away to the island of Crete.

Upon arriving, Jupiter shed his disguise, told Europa of his divinity, and made love to her. She bore him three sons and Jupiter presented his lover with three gifts: the bronze robot, Talos, which guarded Crete's shores, a dog which always captured its prey, and a hunting spear that never missed its mark. Jupiter placed the bull which had served as his disguise into the heavens as the constellation Taurus. When Europa died, he made her a goddess.

Callisto, a moon larger than planet Mercury, is named for a stunning huntress. When Jupiter first laid eyes on this exquisite companion of the goddess Artemis, his fiery passion exploded. Disguising himself as Artemis, the infatuated Olympian took advantage of the unsuspecting Callisto and she bore him a son, Arcas.

Juno soon learned of her husband's secret liaison and transformed Callisto into a frightening she-bear.

Years passed and while hunting one afternoon, youthful Arcas came upon his mother. Callisto saw her son and forgetting her horrible state, ran toward him. Alarmed by the fearsome creature, Arcas raised his spear but just as the boy was about to kill his mother, Jupiter intervened, setting them both into the heavens as the Great and Little Bears (more familiarly known as the Big and Little Dippers).

But Jupiter's actions only fanned Juno's burning rage, for she could not stand to see her rival so honored, and asked her sea-god brother Neptune to forbid these constellations to bathe in his waters. Neptune agreed, and for this reason, the Big and Little Dippers never sink below the horizon.

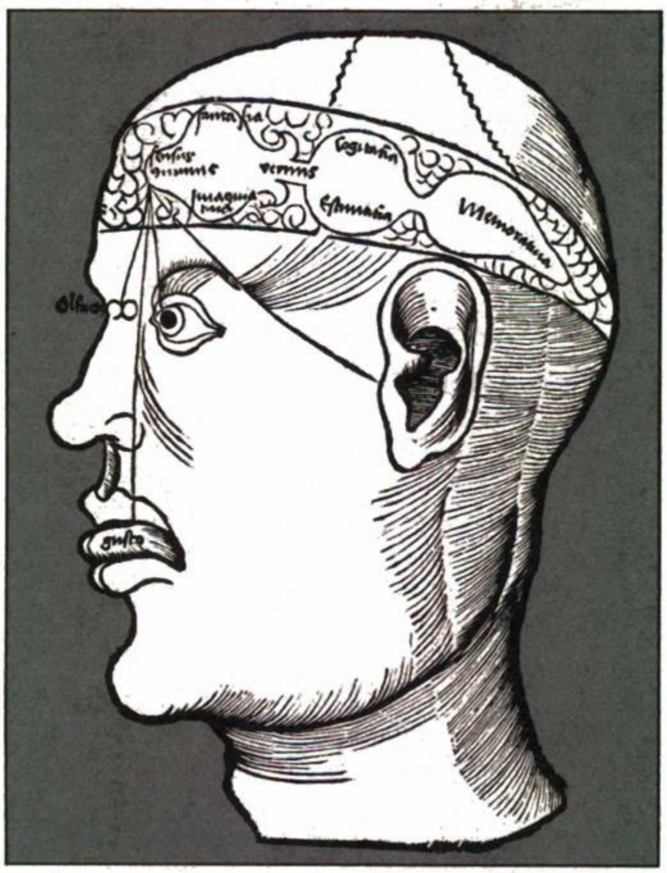
Ganymede, the largest of Jupiter's 13 known satellites, derives its name from the legend of a Trojan boy considered the most beautiful of all mortal men.

When Juno's daughter Hebe, goddess of youth, married the great hero Hercules, she resigned her office as cupbearer to the gods. As a replacement for Hebe, Jupiter selected the child Ganymede.

Taking the form of an eagle, Jupiter snatched the boy away from his playmates on Mount Ida and carried him off to Olympus. Jupiter put Ganymede in Hebe's vacated spot and in order to compensate for the loss of his son, gave the youth's father two divine horses. Jupiter immortalized Ganymede at the moment of the cupbearer's death by placing him among the stars as Aquarius, the waterbearer.

Michael Sheehan Boston, MA

THE BRAIN is the single topic of the September issue of SCIENTIFIC AMERICAN



Is the brain a computer? What is the role of chemistry in brain function? Is the capacity of speech "hard-wired" into the brain? Where in the brain is the mind?

These are questions that will engage your interest in the September issue of SCIENTIFIC AMERICAN.

This issue does not, by any means, tell you "how the brain works." That remains one of the most alluring and baffling questions on the frontier of understanding. The convergence of work in many disciplines—from neurosurgery to linguistics—has begun to put that question, however, in ways that can yield answers.

The deep new knowledge about the brain, gathered at an accelerating rate in recent years, shows this organ to be marvelously designed and capacitated beyond the wonders with which it was invested by ignorant imagination.

Here are the articles:

- The Brain (Introduction)
- The Neuron
- Small Systems of Neurons
- The Organization of the Brain
- The Development of the Brain
- The Chemistry of the Brain
- Brain Mechanisms of Vision
- Brain Mechanisms of Movement
- Specializations of the Human Brain
- Disorders of the Human Brain
- Thinking about the Brain

Each of the authors of this issue has made significant contribution to the growing body of knowledge about the brain. Together they offer a comprehensive exposition of present understanding and chart the way for continuing study.

With this issue the editors of SCIENTIFIC AMERICAN continue a 30-year tradition of devoting each September issue to a single topic of current scientific and public interest. In the other monthly issues our readers enjoy a diversity of articles covering the full range of disciplines.

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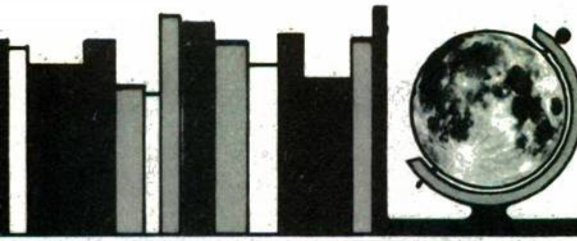
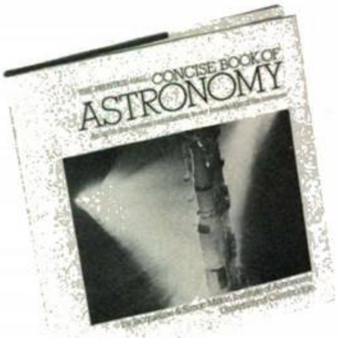


ASTRONOMY bookshelf



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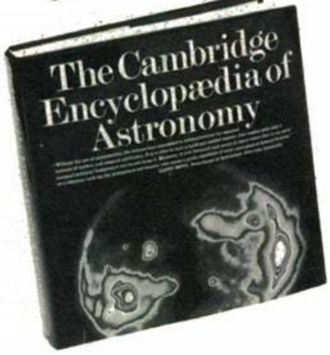

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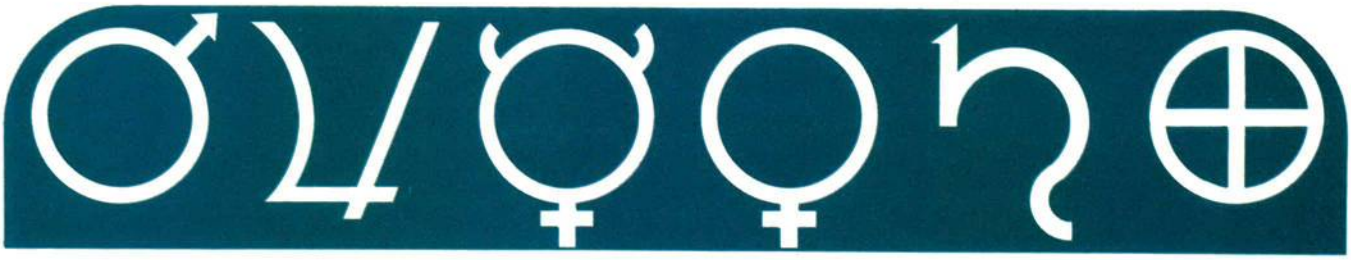


The Moon in Eclipse

September's biggest treats are the lunar eclipse on the 6th and the return of Jupiter in the morning sky. Weather permitting, the eclipse should be a splendid and colorful experience; don't miss it. And Jupiter's arrival heralds the start of another observing season for the planet that's probably the most looked-at of them all.

October Previews

5	Full Moon: harvest moon
6	Ceres at opposition
9	Conjunction of Moon and Aldebaran
10	Mercury at aphelion
12	Last quarter Moon
	Pluto in conjunction with Sun
16	Moon 1° south of Jupiter
18	Moon ¾° south of Saturn
20	New Moon
21	Orionid meteors
28	Last quarter Moon
29	Mercury at eastern elongation

October will be a month of lunar conjunctions, with the Aldebaran and Saturn ones being actual occultations elsewhere in the world.

The mercurian elongation will be one of the year's poorest — a result of our northern latitude, which prevents Mercury from being high in our sky when it is at an aphelic elongation.

Mercury

Having put in its brief appearance last month, Mercury again disappears into the glare of the Sun. Reaching superior conjunction on the 13th of September, it'll pass 1¾° to the north of the Sun. Don't bother looking for the swift inner planet until late next month.

Venus

Venus is also very hard to find, despite its having crossed into the evening sky after superior conjunction on August 25th. The planet's path is taking it southward in declination, so it won't begin to stand out above the western horizon until late in November this year.

Planet Finder gives its coordinates, though, and you might want to go looking for it during daylight hours, provided your scope has setting circles. If it doesn't, you can still locate Venus by offsetting from the Sun. On the 15th of September, Venus will be 22^m37^s to the east and 57′ 48″ to the north of the Sun. Remember to use care when locating the Sun so as not to burn your eyes! Project the image of the Sun and then move the scope the required amount away from it.

But you won't see all that much. Venus is a small round blob, 10 seconds of arc in diameter and showing absolutely no trace of features. Moreover, its image will be swimming around in the heat-distorted air.

Earth

Autumn this year officially commences on the 23rd at 15^h17^m UT. The Sun on this date is crossing the celestial equator on its journey south in declination. This is the equinox, when the length of day and night are the same, with the Sun rising due east and setting due west.

Moon

We gave details about this month's lunar eclipse in last month's issue to give readers a chance to plan, so all we'll do here is mention that there'll be a pretty sunrise eclipse on the morning of the 6th. Easterners don't get the view those in the midwest and west do, but don't pass it up wherever you live.

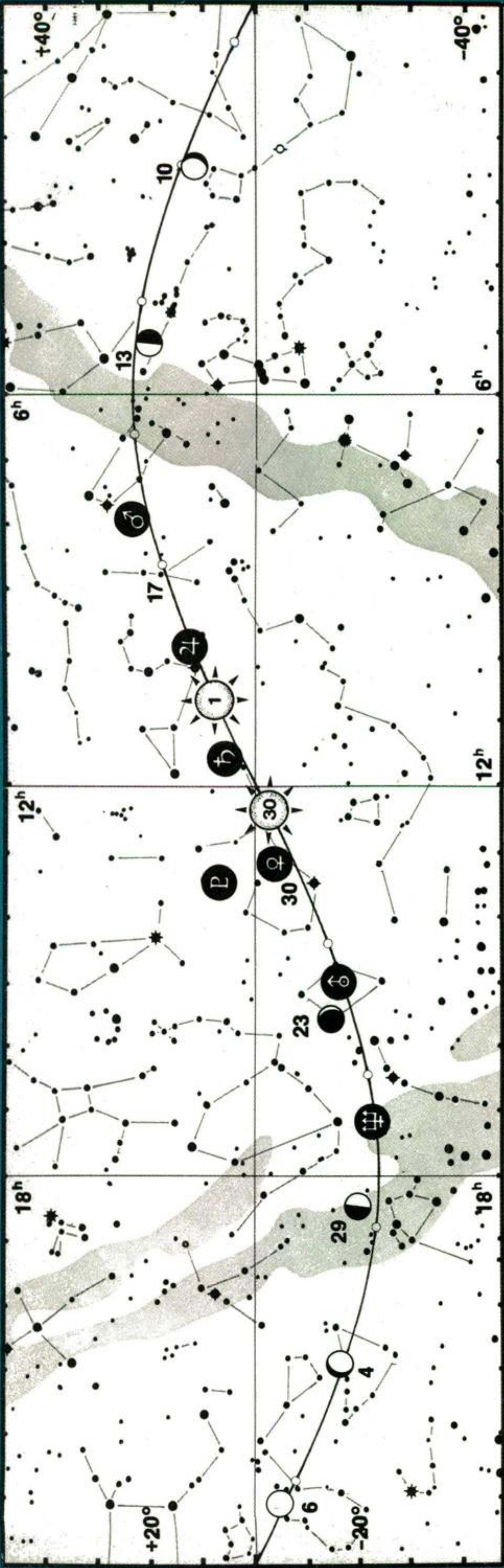
About a week later, on the 12th, there'll be another of the Aldebaran occultations, this one visible from all but the northwestern third of the country. In the Preview box last month we described the path of the northern limit.

Observers living east of about the 85° meridian will see the disappearance at or after sunrise; those west of there see it in a twilight sky more or less bright. The westernmost observers will see the reappearance before sunrise as well.

The disappearance happens on the bright limb, so you'll need to use high power to follow the star right up to the

Planet Finder

September 1979


+40°
-40°
10
13
6h
6h
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1
12h
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18h
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+20°
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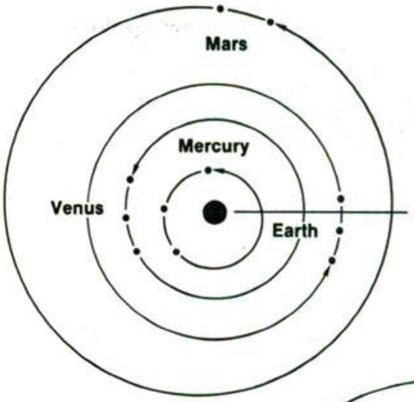
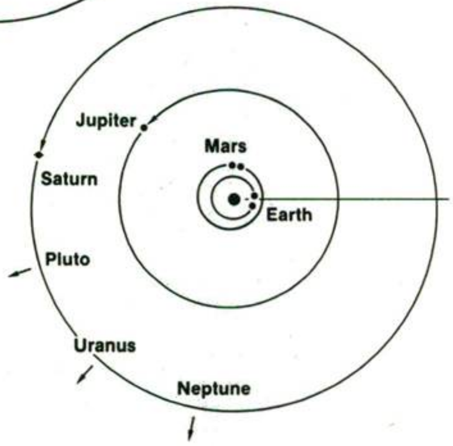
The Planets in Their Courses


Mars
Mercury
Venus
Earth

The positions of Mercury, Venus, Earth, and Mars in their orbits are shown for the beginning, middle, and end of the month. (Mars for the beginning and end only.) The vernal equinox is the line at right.

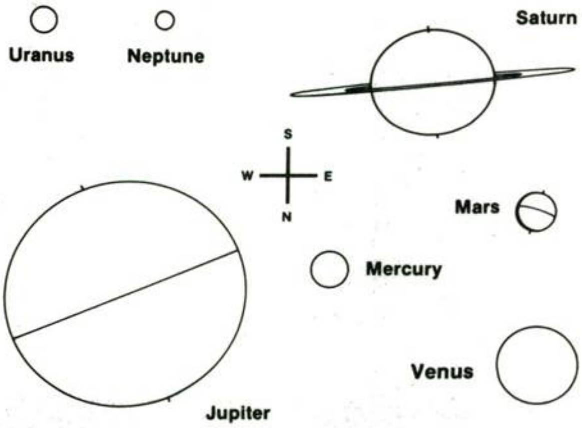
The orbits of Earth, Mars, Jupiter and Saturn are shown at right. Earth and Mars' positions are for the first and last of the month; Jupiter and Saturn for midmonth. The outermost planets' directions are indicated.

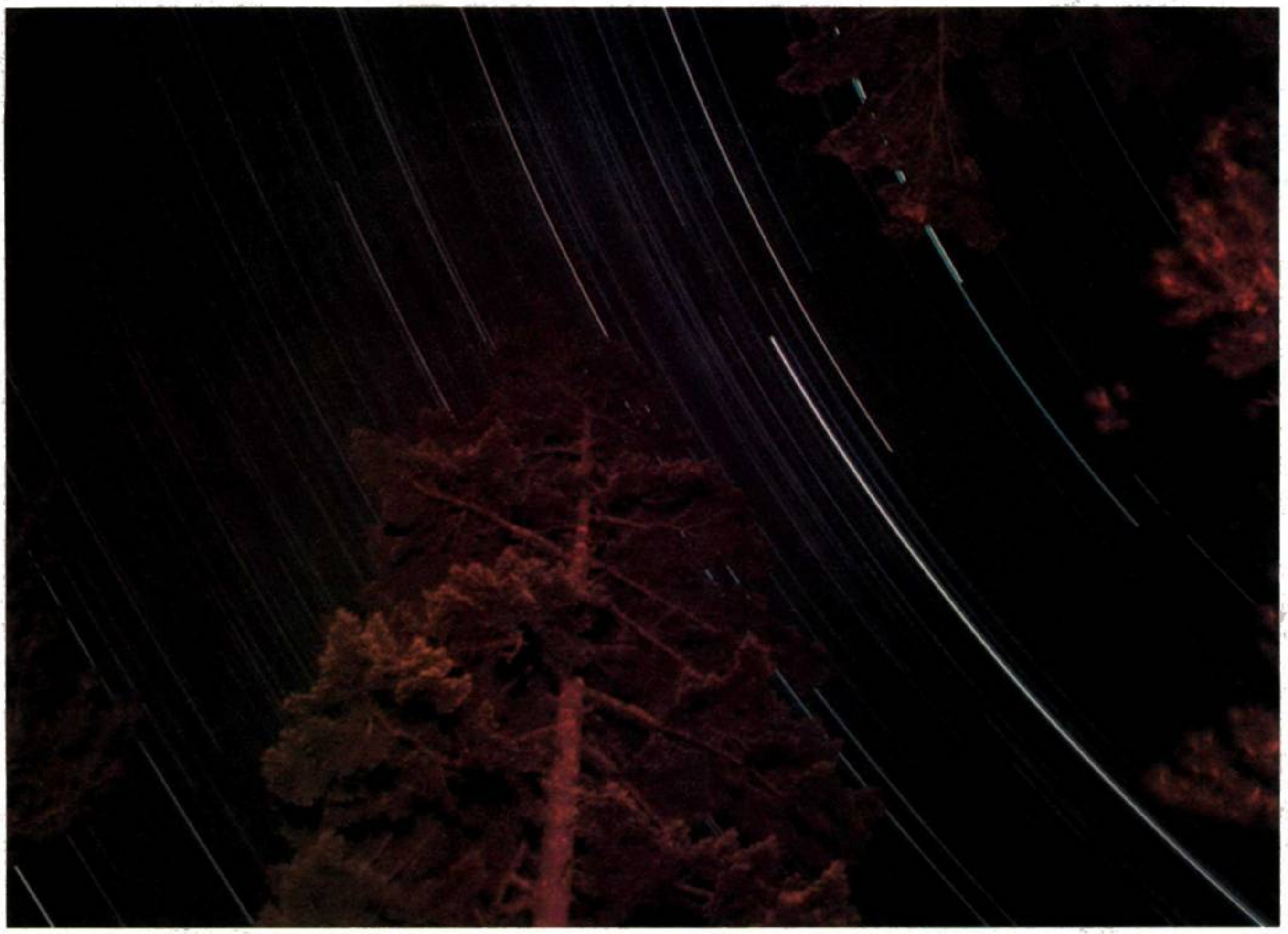

Jupiter
Mars
Saturn
Earth
Pluto
Uranus
Neptune

Positional Data

Planet	Date	R.A. (1979.8)	Dec.	Mag.	Distance (AU) from Earth	Distance (AU) from Sun
Mercury ☿	10	$11^h 02.7^m$	8°01.1′	-1.4	1.36	0.36
	20	$12^h 09.6^m$	0°09.2′	-1.0	1.40	0.41
	30	$13^h 09.8^m$	-7°24.1′	-0.5	1.37	0.45
Venus ♀	10	$11^h 28.8^m$	4°53.1′	-3.5	1.72	0.72
	30	$12^h 59.8^m$	-5°13.8′	-3.4	1.69	0.72
Mars ♂	15	$7^h 44.1^m$	22°06.5′	+1.5	1.83	1.55
Jupiter ♃	15	$9^h 58.2^m$	13°11.8′	-1.3	6.25	5.35
Saturn ♄	15	$11^h 18.0^m$	6°29.4′	+1.2	10.40	9.39
Uranus ⛢	15	$15^h 02.5^m$	-16°54.3′	5.9	19.25	18.71
Neptune ♆	15	$17^h 07.5^m$	-21°29.6′	7.8	30.33	30.28
Pluto ♇	15	$13^h 30.5^m$	8°28.3′	14.0	31.07	30.21

Telescope View


Uranus
Neptune
Saturn
S
W
E
N
Mars
Mercury
Venus
Jupiter



Jonathan Dudey was camping on the coast of Oregon last October when he took this 3-hour exposure of star trails behind the campfire-lit conifers. The view is toward the west. He used a 40 mm lens at f/2, and the film was Kodachrome 64.

moment of immersion. The Moon at the time will be 20.3 days old (waning gibbous) and 63% lit.

Mars

The red planet's dash across the constellation Gemini is particularly easy to follow as it approaches and passes south of Castor and Pollux. By the end of the month, you'll see the planet closing in on the Beehive Cluster, so recently vacated by Jupiter.

At magnitude +1.5, Mars is still not exactly an overpowering object. You'll have no trouble making it out, though, and binocular views will be especially nice.

Telescopically, the planet has a disk just over 5″ of arc in diameter on the 15th. About now, you may be able to discern the beginning of a slight out-of-roundness in the disk. This isn't an optical illusion: although Mars orbits the Sun farther out than we do, the planet is still close enough to display a small phase effect when it and the Sun are about 90° apart in our sky. We aren't yet at the point where the phase is maximum (that comes in mid-November), but the disk is now only about 91% to 92% lit. Keep an eye on Mars over the next several weeks and watch it change.

Jupiter

Back out of the solar blaze and once more in view, Jupiter will put on a good show this fall and winter. On the 26th of September, Jupiter will be less than half a degree north of Regulus. This will be a pretty sight for any observer, however equipped. The star is of magnitude -0.7, the planet -1.3. Earlier, on the morning of the 18th, you'll see a slim crescent moon above and near Jupiter and Regulus.

Those who have been following the eclipses and transits of the jovian moons will notice how the disappearances and reappearances have now shifted to the opposite side of the planet. Previously, the shadow of the planet extended out to the east; now it extends to the west.

This month isn't the best for eclipse watchers because of the short time between Jupiter-rise and sunrise, but try looking for Io's disappearance on the 16th at 9^h57^m UT. At 11^h24^m UT on the same day, Europa will also disappear, but this comes after sunrise for people in the eastern part of the country. Callisto blinks out on the 21st at 11^h30^m UT, and the same visibility proviso holds.

Saturn

Saturn is in conjunction on the 10th and so will be out of view during September, though late in the month, you may spot it low in the east just before sunrise.

Universal Time

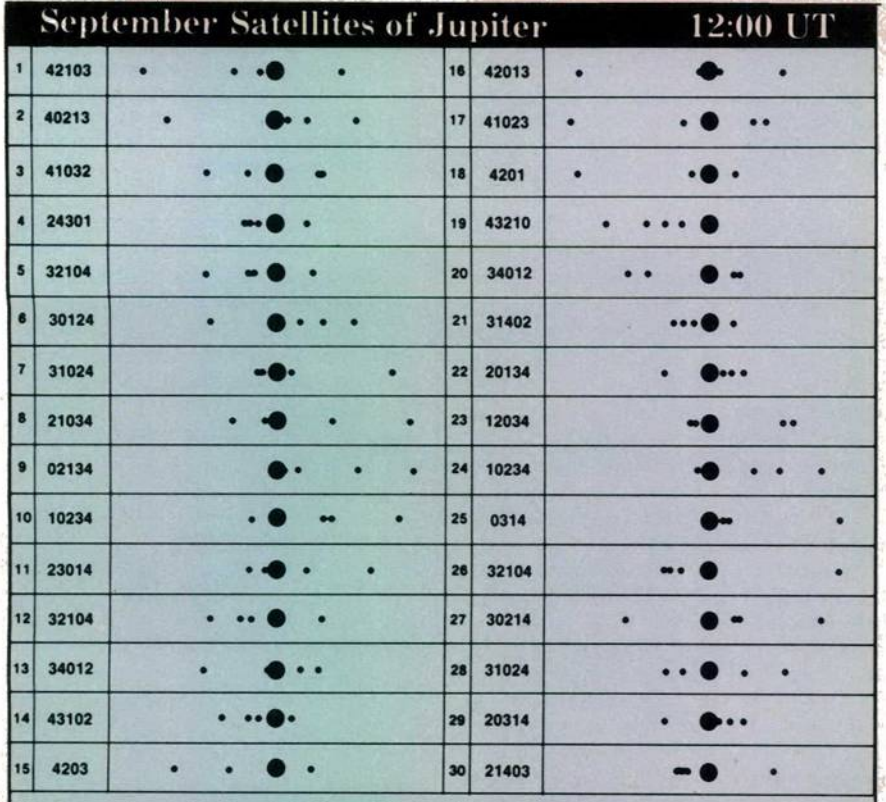
Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times given in Sky Almanac are in UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5; MDT, 6; PDT, 7; Alaska and Hawaii, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then the time in EDT would be 11 p.m. June 6. Likewise, 03:00 UT on Sept. 2 becomes, in PDT, 8 p.m. on Sept. 1.

Lunar Phases

Full Moon: September 6th, at 10^h59^m UT, in Aquarius. Last quarter: Sept. 13th, at 6^h15^m, in Taurus. New Moon: Sept. 21st, at 9^h47^m, in Virgo. First quarter: Sept. 29th, at 4^h20^m, in Sagittarius. Perigee: Sept. 6th at 5^h; apogee: Sept. 19th, at 10^h.

This splendid photo of Jupiter corresponds to what most people would see visually with a 10″ or 12″; with practice and experience, you'd pick up most of these details in a 6″. Jim Rouse used his 8″ f/7, High Speed Ektachrome (5 second exposure), and eyepiece projection.

September Satellites of Jupiter 12:00 UT



1	42103	16	42013
2	40213	17	41023
3	41032	18	4201
4	24301	19	43210
5	32104	20	34012
6	30124	21	31402
7	31024	22	20134
8	21034	23	12034
9	02134	24	10234
10	10234	25	0314
11	23014	26	32104
12	32104	27	30214
13	34012	28	31024
14	43102	29	20314
15	4203	30	21403

The four major satellites of Jupiter orbit the planet in periods ranging less than 2 days to 17 days. You'll see them change position from night to night. This table shows the approximate position of the moons each night. The column at the far left shows the date; the second column gives the names of the moons (Jupiter = 0, Io = I, Europa = 2, Ganymede = 3, Callisto = 4). The third column shows the satellites' positions as they appear through an inverting telescope; south is at the top.

Uranus

Dim little Uranus is moving southeastward in the sky away from Alpha (α) Librae. Still within one binocular field of the star, you should be using at least a small telescope to get much of a view.

Set your scope on Alpha Librae and then sweep east 4° until you see 5.3 magnitude Nu (ν) Librae. Uranus will be a 5.9 magnitude dot about a third of a degree south-southwest of Nu. Uranus has a disk, but it's only 2.6″ of arc across.

Neptune

Neptune always looks like Uranus, only not as good! At the start of September, Neptune is 3¼° west of 4.4 magnitude Xi (ξ) Ophiuchi (R.A. 17^h 18^m, Dec. -21° 3.5′, 1950 coordinates). Over the month, it'll gradually move towards the east.

Your best approach to locating the planet is to place Xi at the north center of your field of view. Then sweep slowly westward, using a moderate-power eyepiece. Neptune has a 2.4″ of arc disk and will be at magnitude 7.8.

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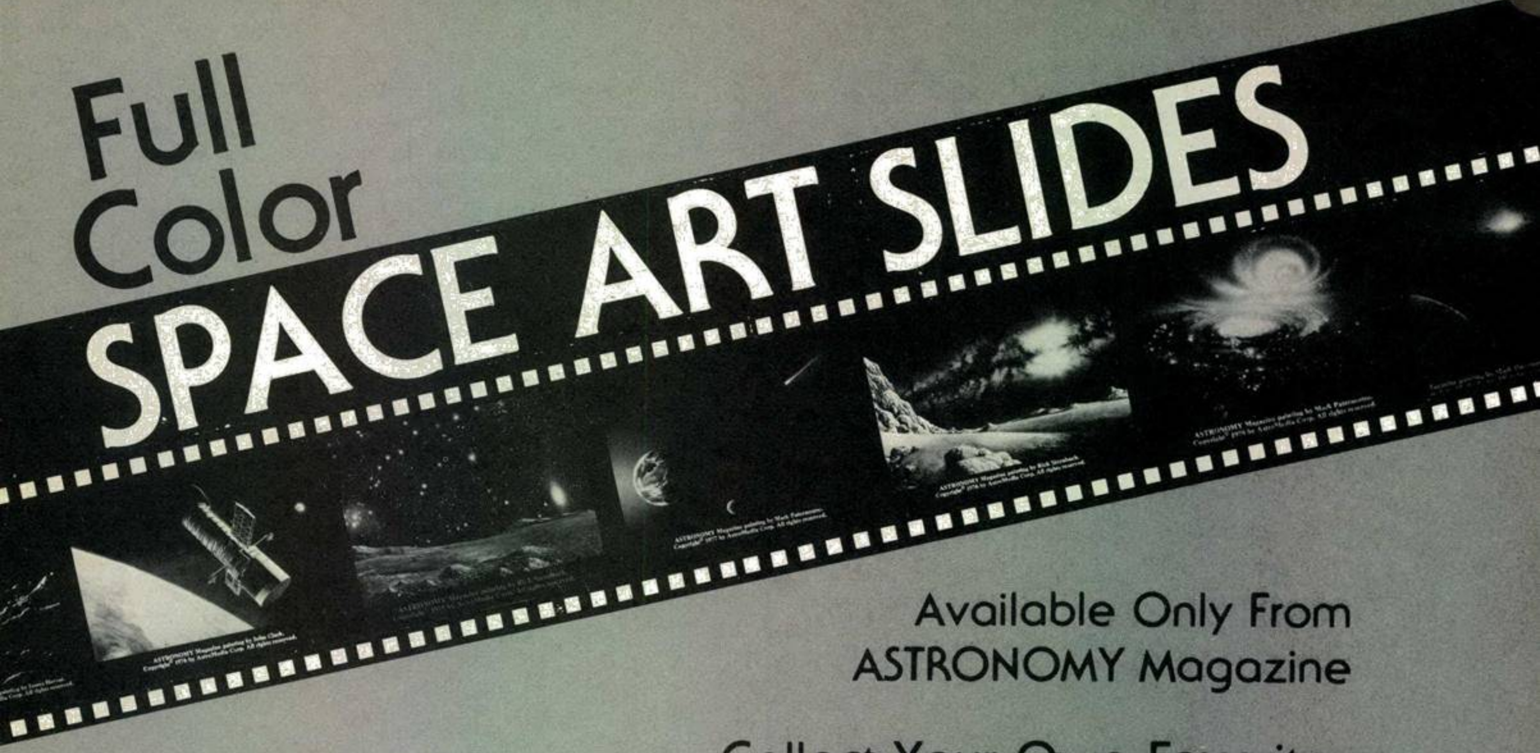

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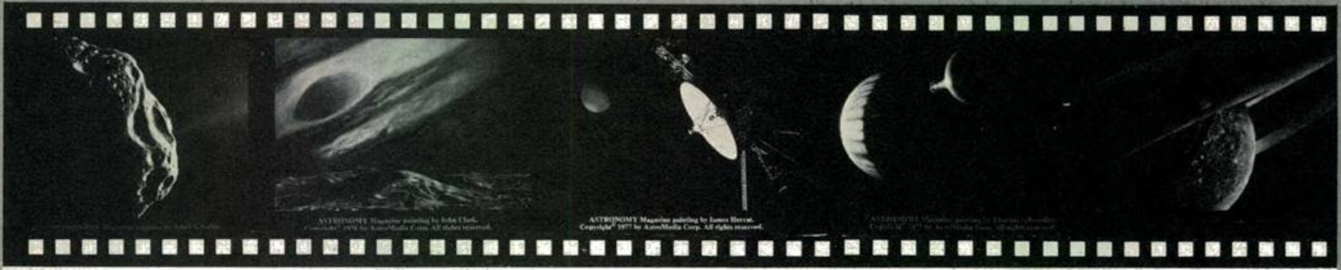

Adolf Schaller
- ☐ AS-01 Uranus' Rings July 1977, cover
- ☐ AS-02 Martian Duststorm March 1977, pp. 36 & 37
- ☐ AS-03 Solar Chromosphere September 1977, p. 35
- ☐ AS-04 Triple Star System September 1977, p. 12
- ☐ AS-05 Asteroid Belt September 1977, pp. 6 & 7
- ☐ AS-06 In The Beginning January 1976, pp. 6 & 7
- ☐ AS-07 Vallis Marineris January 1977, pp. 12 & 13
- ☐ AS-08 Spiral Galaxy April 1976, p. 19
- ☐ AS-09 Colliding Galaxies April 1976, p. 22
- ☐ AS-10 Asteroid Eros June 1976, pp. 6 & 7
- ☐ AS-11 Venus Probe August 1976, cover
- ☐ AS-12 Red Giant December 1976, p. 27
- ☐ AS-13 Radio Galaxy Core November 1976, p. 22
- ☐ AS-14 Supernova Explosion September 1975, p. 52
- ☐ AS-15 Saturn From Above January 1975, p. 30

Thomas Schroeder
- ☐ TS-01 Enzmann Starships August 1977, pp. 6 & 7
- ☐ TS-02 Light Sail April 1978, pp. 6 & 7

Rick Sternbach
- ☐ RS-01 Exploding Galaxy May 1976, pp. 12 & 13
- ☐ RS-02 Cosmic Gas Cloud May 1976, p. 30
- ☐ RS-03 Erupting Quasar May 1976, pp. 6 & 7
- ☐ RS-04 View From Distant Planet December 1975, pp. 12 & 13

Mark Paternostro
- ☐ MP-01 Tharsis Eruption October 1977, pp. 20 & 21
- ☐ MP-02 Terraformed Moon May 1978, cover
- ☐ MP-03 Brown Dwarf April 1978, pp. 20 & 21
- ☐ MP-04 Swarms of Stars March 1978, pp. 6 & 7
- ☐ MP-05 Matter vs. Antimatter March 1978, pp. 20 & 21
- ☐ MP-06 Formation of Gas Giant December 1977, pp. 6 & 7
- ☐ MP-07 Collision Course With A Comet December 1977, pp. 20 & 21
- ☐ MP-08 Solar Polar Probe August 1977, p. 19
- ☐ MP-09 Black Hole February 1977, p. 27
- ☐ MP-10 Black Hole, Asteroid Collision February 1977, cover

James Hervat
- ☐ JH-01 Pluto February 1977, pp. 20 & 21
- ☐ JH-02 Uranus From Voyager February 1977, pp. 6 & 7
- ☐ JH-03 Formation of Mare Imbrium September 1976, pp. 6 & 7

Anne Norcia
- ☐ AN-01 Mercury Terraformed May 1978, pp. 20 & 21
- ☐ AN-02 Red Dwarf Explosion July 1978, cover

John Clark
- ☐ JC-01 Jupiter From Io February 1976, pp. 6 & 7
- ☐ JC-02 Space Telescope November 1976, pp. 6 & 7
- ☐ JC-03 Starship To Antares August 1974, p. 4 & 5
- ☐ JC-04 Starship To Zeta Reticuli December 1974, p. 4 & 5

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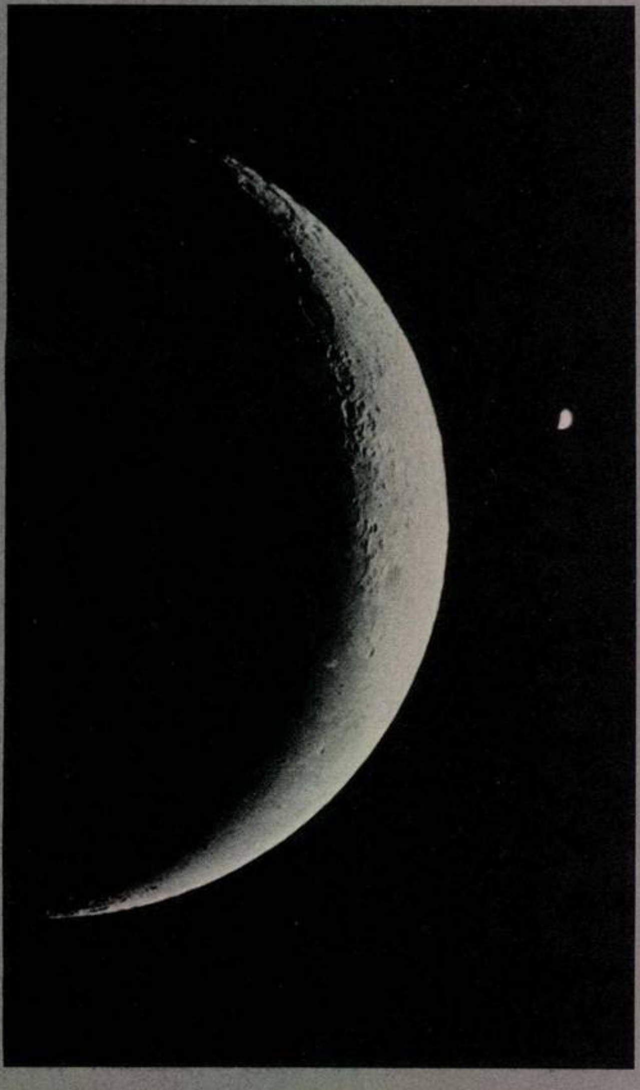
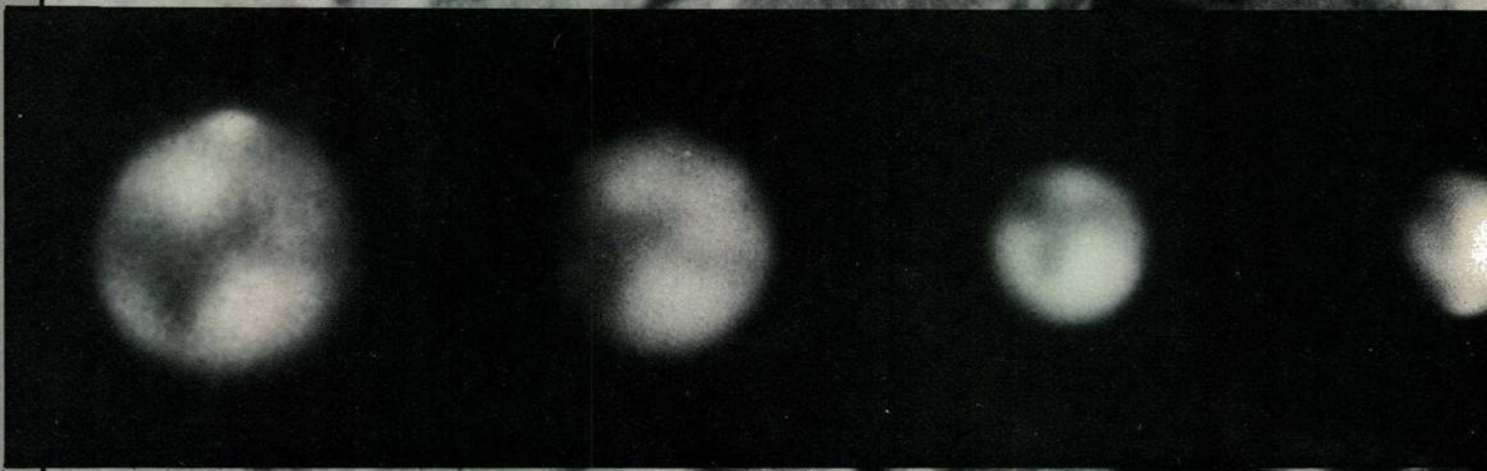


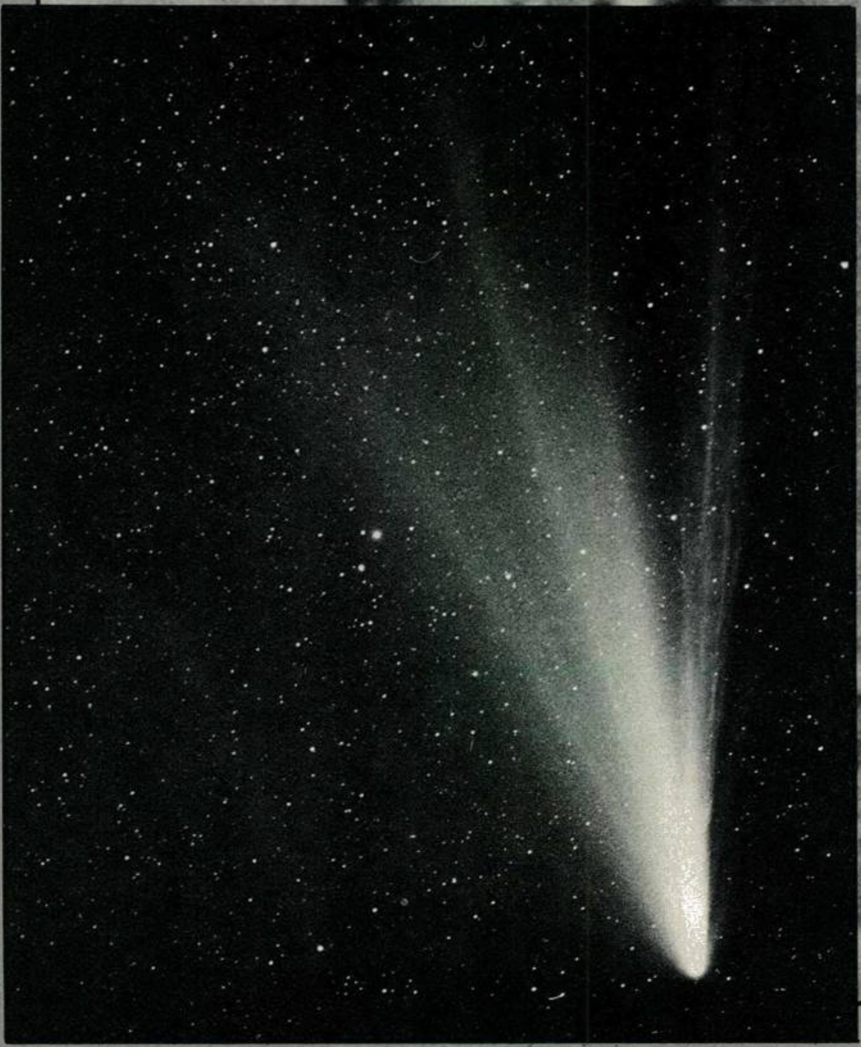
If there's one part of astronomy that captures everyone's attention and admiration, surely it's astrophotography! A fine astrophotograph can impress even the most incurious. Maybe it's because the subject matter appears unusual, but on the other hand, perhaps these people are sensing some of that awe of the infinite that motivates most of us who love astronomy. Whatever the reason though, there's no doubt that a good astrophotograph leaves few people unaffected.

Because of the great variety of phenomena the heavens present, effective and striking astrophotographs can be taken with virtually any sort of equipment. You don't have to have a 12″ reflector with a cold camera located at a faraway site under a black sky. Astrophotography can start in your backyard with little more than an ordinary camera and no telescope at all. Naturally, having a solid, equatorially-mounted scope widens the range of subjects you can tackle, but even the most modest small scope can yield effective lunar photos if you shoot into the eyepiece with short exposures. The biggest mistake you can make is under-rating simple equipment.

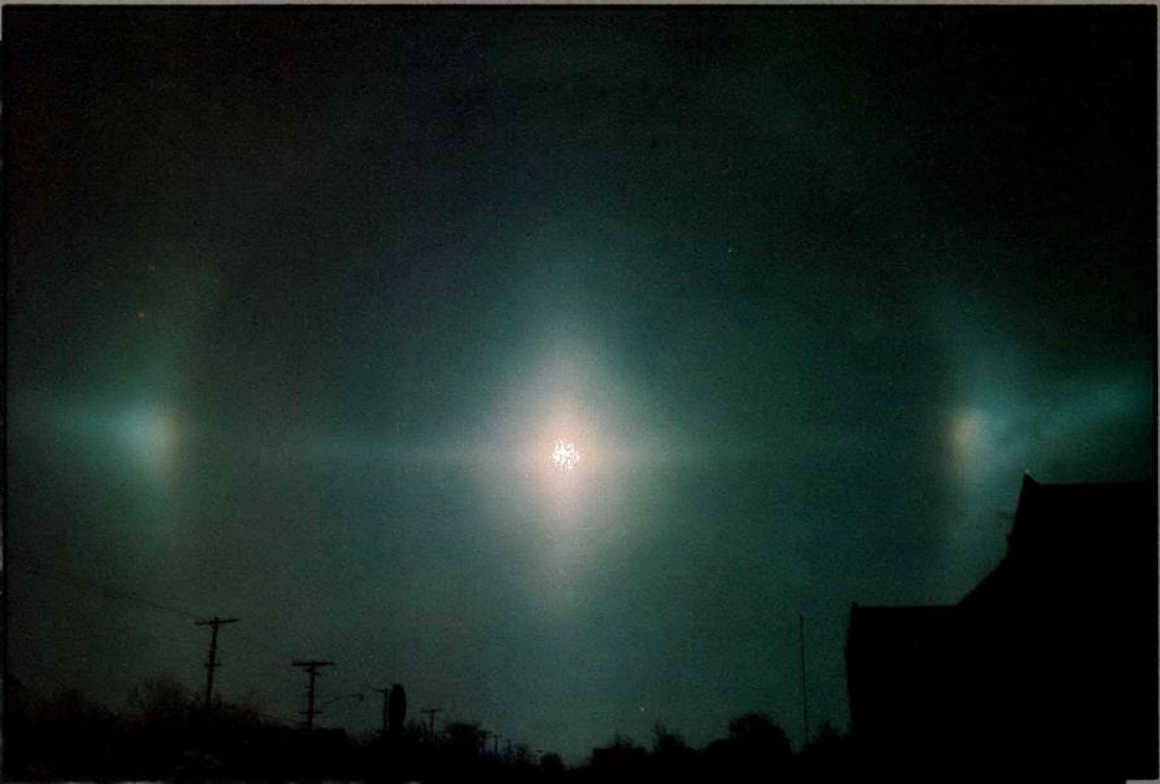
On the following pages, you'll find an assortment of photographs we've received over the years. We think these pictures — and the dozens more we didn't have room to include — demonstrate the range of astrophotography. They were all carefully made, and the pride their makers take in them is obvious and justified. Some photographs seen here required considerable efforts with elaborate equipment; others were almost snap-shots. But each of them shows a devotion to preserving and sharing that particular wonder somebody felt when confronted with the universe.

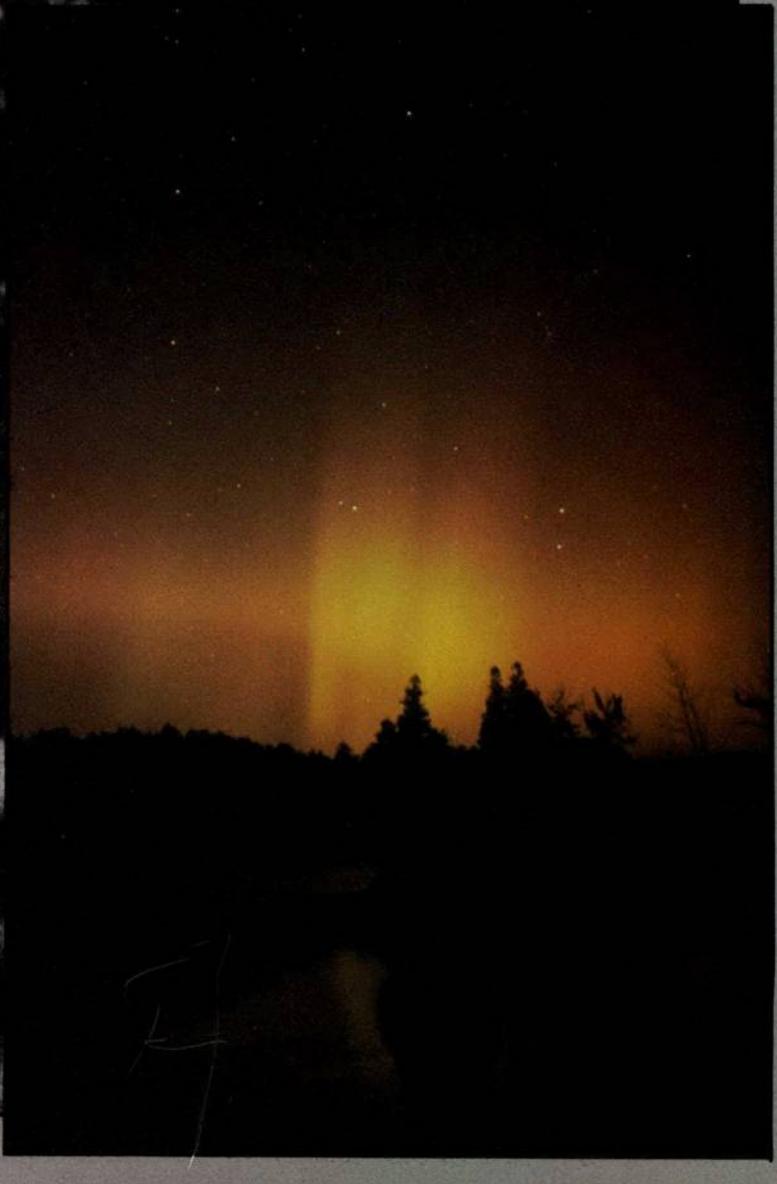
Very striking and impressive even to the general public, planetary conjunctions and occultations are deservedly popular among astrophotographers. What's more, they're easy to shoot. Here we see the Moon and Venus just before the planet's occultation on December 26th, 1978. Boris Starosta snapped the photo by aiming his camera (and its 50 mm, f/1.4 lens) into the 40 mm eyepiece of his 6″, f/8 Newtonian reflector. The film was Tri-X and the exposure was 1/30 second.





Left top: Mars' distance at opposition varies due to the planet's orbital eccentricity as this series of shots taken at the last four oppositions shows clearly. Photo series like this are informative and fun to do (photos by Bob Kimmel). Left bottom: Though rare in recent years, spectacular comets make fine photo-subjects. Comet West (seen here) was taken with a 135 mm lens riding piggy-back on a telescope, and Tri-X film. The exposure time was 5 minutes (Marvin Mayo & George Carlisle). Right top:





Sundogs, rings, halos, and other parhelic phenomena are very common; look for them whenever you're outside. Your meter will give you the correct exposure (Alan Dyer). Right bottom: Aurorae are also common, at least in the higher latitudes, and especially now that solar activity is on the increase. Use a fast film, a wide aperture, and an exposure between 5 and 60 seconds (J.M. Woodland). Background: The Moon is a popular subject because its brightness allows short exposures and you needn't have dark skies or large apertures (Tim Tomljanovich).

Above: M-51, the Whirlpool Galaxy in Ursa Major, is a favorite deep-sky object that is quite a challenge to photograph. Bill Iburg used ASA 400 slide film in a cold camera attached to his 14" Schmidt-Cassegrain telescope. Below: Even the simple camera-on-a-tripod can provide stunning views like this of Orion rising. The exposure was 15 minutes at f/2.8 on ASA 200 slide film with a 50 mm lens (J.M. Woodland). Right top: The Magellanic Clouds are two satellite galaxies of the Milky Way. Best seen from well south of the equator, they were caught by Rev. Ronald Royer's 50 mm, f/1.4 lens on ASA 200 slide film using a half hour guided exposure. Far right: The southern Milky Way in Crux was the target for this, another of Rev. Royer's photos. ASA 200 film again, but with a carefully guided, hour-long exposure using a 105 mm lens at f/2.5. Near right: Les Yuill captured one of the many ruddy regions of ionized hydrogen in the sky, M-17. He used ASA 100 slide film with his 8", f/5 Newtonian reflector and a 25 minute exposure.

Above: The familiar Big Dipper's low elevation offered Allan Burke a chance to shoot it along with city lights on the horizon. A tripod, fast film, a lens set wide open, and a few seconds' exposure will grab easy and impressive shots like this. Below: When a prominent constellation or asterism is rising or setting, see if you can frame it with a foreground object, the results can be very pretty! Here, a tree lightly dusted with snow stands out gauntly against the sky (Phillip H. Niles).

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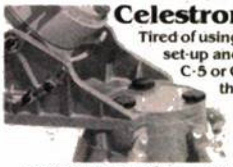

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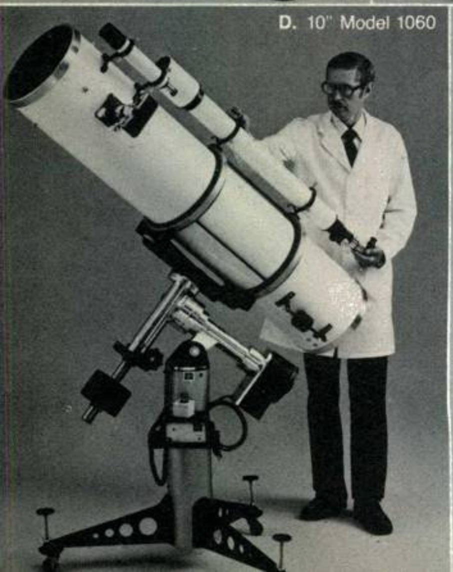
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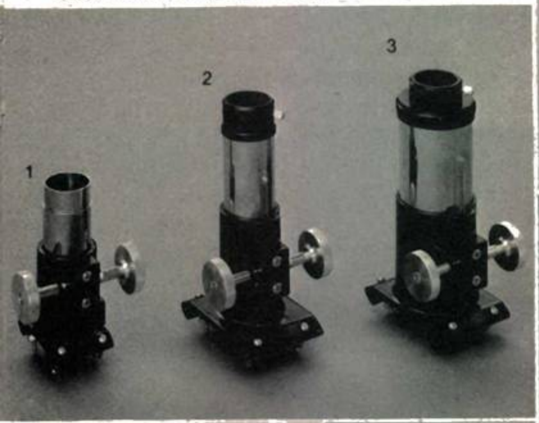

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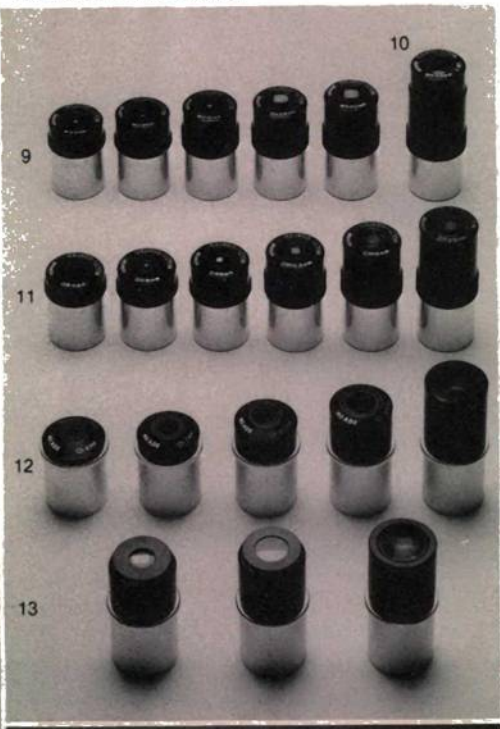

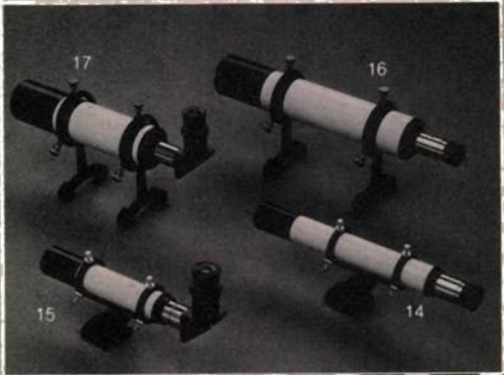

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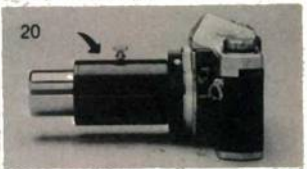

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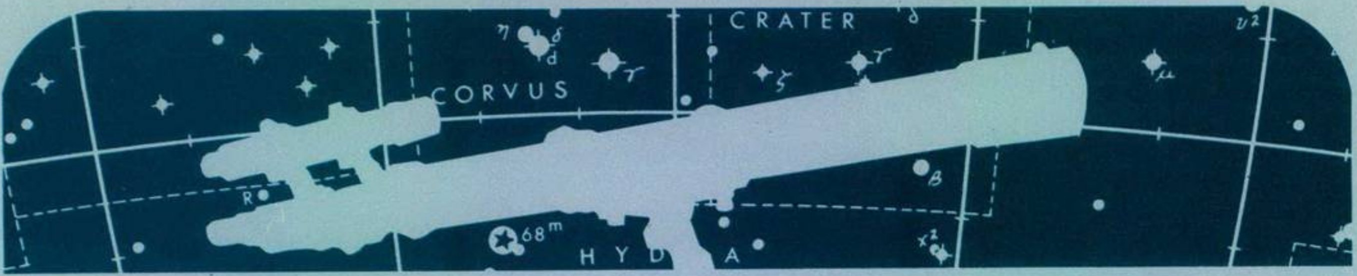
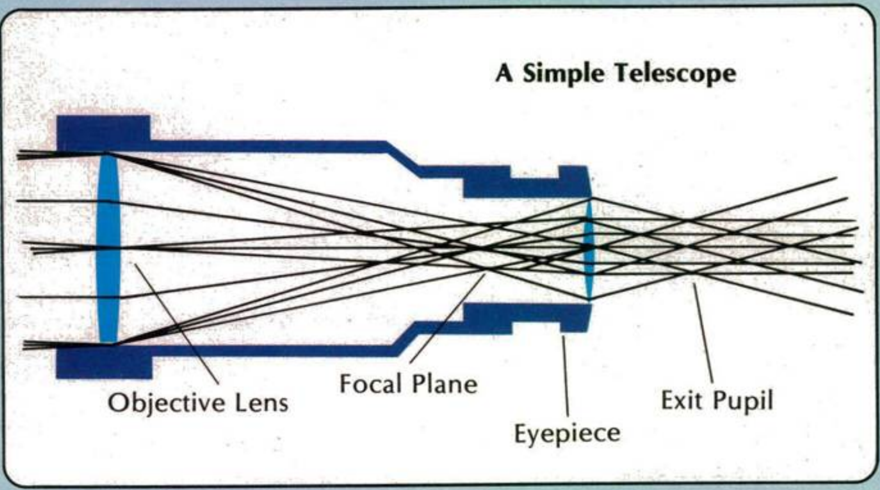


Visual Image Brightness

by
Philip L. Plante


A Simple Telescope

If a friend were to tell you that under the right conditions, certain celestial objects appear as bright in your telescope as they do in the 200-inch telescope on Mount Palomar, you'd probably think he was crazy. After all, every observer worth his photons knows that the light gathering power, or LGP, of a telescope is equal to the ratio of the aperture area of the telescope to the maximum pupil area of the eye. And the larger the aperture area, the greater the light gathering power of the telescope. You could even show him Table 1 which illustrates how light gathering power increases with aperture size.

In fact, your crazy friend is right! While the light gathering power of a telescope is an impressive statistic, it alone is not sufficient to explain the apparent visual brightness of an image in the telescope. So how does a telescope affect the visual brightness of the images it forms? And what role does the aperture size of the telescope play? To answer these questions, let's start with a little background on telescope optics.

The Exit Pupil and Normal Magnification

If you've been around telescopes for any length of time, you've probably run across the term *exit pupil.* The exit pupil may be easily understood if you keep in mind that a lens will form an image of every object in front of it provided that light from the object reaches the lens. Thus the *eyepiece* lenses of a telescope form an image not only of what the telescope is viewing, but also of the objective lens itself illuminated by the light which it admits into the telescope. The exit pupil is just this image of the objective lens formed by the eyepiece.

In order to know how much of the light converging through the exit pupil enters your eye, you have to know the diameter of the exit pupil. You get this by simply dividing the diameter of the objective by the magnification being used. This relation is important because the exit pupil decreases in size as the magnification increases. The magnification at which the exit pupil diameter equals your maximum eye pupil diameter (usually 7 mm or 0.28 inches) is called *normal magnification.* For powers above normal magnification, the exit pupil is smaller than the eye pupil, while below the normal magnification, the exit pupil is larger than the eye pupil. Table 1 lists the normal magnifications for several telescopes of different apertures.

The size of the exit pupil in relation to the eye pupil size is important for determining the visual brightness of objects viewed through the telescope. The mechanism of visual image brightness, however, is different for point sources such as stars than it is for extended sources such as the Moon, nebulae, and galaxies.

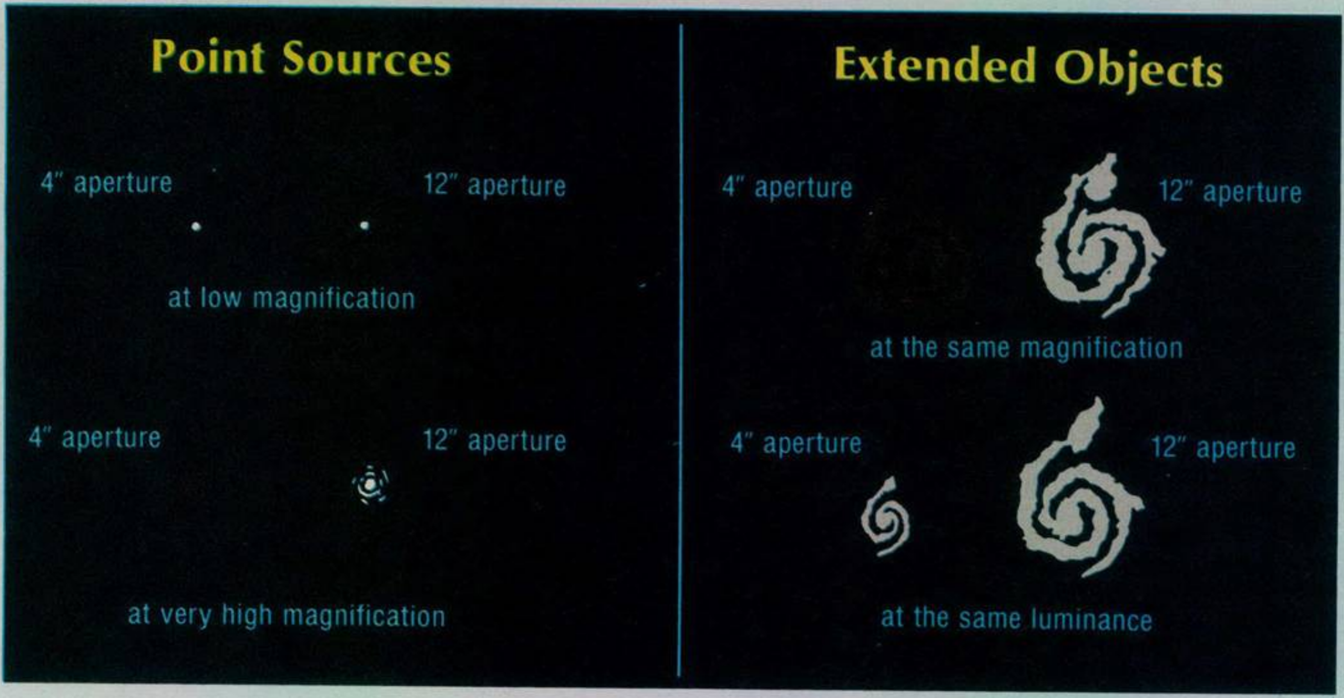
Brightness of Point Sources

A *point source* is any source of light without a detectable area. In astronomy, individual stars are essentially point sources since the area of even the largest nearby stars cannot be resolved by a single earthbound telescope. The image of a star in your eye is essentially the same size whether a telescope is used or not. Thus the sensation of brightness is simply related to the amount of light concentrated in the star's image. Since the telescope gathers more light than the eye, it puts more light into the point image.

But how much brighter will a star's image in a telescope be? The easiest way to answer this is to compute the *magnitude gain* of the telescope. The magnitude gain is simply the difference between the magnitude of the star and the magnitude of its image in the telescope as perceived by the eye.

First, a magnitude difference of one is equal to a factor of 2½ in the amount of total light received from two sources. (See "Magnitude & Brightness," ASTRONOMY, June 1979.) Thus, a telescope receives 2½ times more light from a first magnitude star than from a second magnitude star. In general, if two stars have a magnitude difference of "m", then the telescope receives 2½ to the mth power, or $(2\frac{1}{2})^m$, times more light from the brighter star than from the dimmer one.

If "m" represents the magnitude difference between a star (as seen by the eye) and its image in a telescope,



then we have the following simple relation:

$$(2\tfrac{1}{2})^m = \text{LGP}$$

We can solve for "m" using logarithms which yields:

$$m = (1.09 \times \log_e (\text{LGP}))$$

in which $\log_e$ refers to the "base e" (2.717), or natural, logarithms. If you prefer not to fool with logarithms, Table 1 lists the values of "m" for the more common aperture sizes.

The factor "m" is the magnitude gain of a telescope of given LGP and relates the magnitude of the star and its image as follows:

$$\text{Magnitude of the Image} = \text{Magnitude of the Star} - m$$

In an 8-inch telescope, for example, the magnitude gain is 7.3. By the above formula, a star of magnitude 13.3 would have an image magnitude of 13.3 - 7.3 = 6, or sixth magnitude. In other words, the 13.3 magnitude star in the scope would look like a 6.0 magnitude star with the naked eye. Normally, your eye will detect a star no dimmer than sixth magnitude. The image of any star with a magnitude greater than 13.3 will therefore be too faint to be seen in an 8-inch telescope. 13.3 thus corresponds to the limiting stellar magnitude (LSM) or faintest star detectable in an 8-inch telescope. Table 1 lists the values of the LSM for the more common aperture sizes.

Unfortunately, there is a small catch in the preceding analysis. If you observe a star using a power below the normal magnification of your telescope, the exit pupil will be larger than the eye pupil and not all of the light gathered by the telescope will get into your eye. This effectively reduces the LGP and the magnitude gain of your telescope. The lower the power, the larger the exit pupil and the more light that's lost. The message here is to *use only powers equal to or greater than the normal magnification of your telescope* in order to maximize the brightness of point sources.

The advantage of larger apertures for observing point sources can be readily seen by glancing at Table 1. As the aperture increases, so does the magnitude gain and the limiting stellar magnitude. Obviously, when it comes to observing faint stars, the larger the telescope, the better. But remember, only powers above the normal magnification fully utilize the LGP of the telescope.

Brightness of Extended Sources

An *extended object* is any source of light with a detectable extent or area. The sensation of brightness is now related not to the total light alone, but to the total light received *divided* by the apparent area of the source. This quantity is known as the surface brightness or "luminance."

To understand how a telescope affects the apparent (or sensed) brightness of an image, we'll compare the luminance of the telescopic image to that of the object itself. Suppose you observe an extended source of uniform luminance (such as a nebula) through a telescope. While the telescope collects LGP times more light than the eye, it also magnifies the apparent area of the object by a factor equal to the square of the magnification being used. The luminance of the image in the telescope relates to the luminance of the object as in the following formula:

$$\text{Luminance of Image} = \text{Luminance of Object} \times \frac{\text{LGP}}{\text{Mag.}^2}$$

At the normal magnification, the ratio of the light gathering power to the square of the magnification is precisely one. Then by the above formula, the luminance of the image will just equal the luminance of the object itself. That is, the gain in light caused by the LGP of the telescope is counter-balanced by an equal gain in the magnified area of the image.

In a case where the power being used exceeds the normal magnification, the ratio of the LGP to the square of the magnification is *less* than one. As a result, the luminance of the image will be less than the luminance of the object.

This result is surprising since the exit pupil, in this case, is smaller than the eye pupil so that all of the light gathered by the telescope is admitted into the eye. The lower luminance results from having magnified the area of the object by an amount exceeding the light gathering power of the telescope. Further magnification increases will only result in further decreasing the image luminance, producing a dimmer image.

The above results often seem surprising to users of astronomical telescopes. However, those who use a telescope during the day for terrestrial viewing can verify that images do indeed look less bright in the telescope. In fact, if the telescope increased the luminance of extended objects, daytime terrestrial observing would be impractical because bright objects would tend to become blinding.

But what happens at magnifications less than normal magnification? In this case, the ratio of the LGP to the square of the magnification is greater than one and the luminance of the image should therefore exceed the luminance of the object itself. Unfortunately, this is not the case. As we described for the point source before, the light gathering power of the telescope is effectively reduced when the exit pupil diameter exceeds the eye pupil's diameter. This reduction in the effective light gathering power *exactly* counteracts the expected gain in the luminance of the telescopic image so that its luminance can equal, but never exceed, the luminance of the object itself.

It is interesting to note the contrasting behavior of point sources and extended sources in the telescope. Point sources are brightest at powers at and above the normal magnification. Extended sources, conversely, achieve peak luminance only at powers at and below the normal magnification. Only at the normal magnification, then, is the stimulus of brightness for both point and extended objects at maximum.

The Night Glass Effect

The results of the preceding section lead to a very serious dilemma: if the luminance of an image seen in a telescope can never exceed the luminance of the object itself, you should never be able to see an extended object in a telescope of *any* aperture that couldn't be seen by the naked eye. But as every observer knows, a telescope of even modest aperture reveals hundreds of extended deep-sky objects that are invisible to the unaided eye. Obviously, something hasn't yet been considered, and that one element — a very important one — so far neglected is the human eye itself.

Studies on the behavior of the eye under conditions of very dim lighting show that when viewing a faint object against a dark background, the minimum or "threshold" amount of luminance required for the eye to see an object depends on the angular size of the object. The larger the angular size, the lower the luminance threshold becomes. This effect, known as the *night glass effect*, holds true up until the object subtends, in the case of circular objects, about five degrees at the eye. Increasing the object's size beyond this produces no further effect. While this effect is well-known only for circular objects, it's reasonable to assume that it holds for other shapes in approximately the same manner also.

The night glass effect has an obvious application to the telescope. The telescope's magnifying power increases the apparent size of small, faint celestial objects and thus reduces the amount of luminance required for the eye to see them. But to fully understand the phenomenon of visual image brightness in the telescope, we must consider not only the night glass effect but also the effect of the telescope on the luminance of the image.

Below the normal magnification, the luminance of both the object and its image in the telescope are equal. Since the image is larger, however, the amount of luminance needed to see it is lower and it will appear brighter to the eye. It is just this phenomenon which produces the apparent increase in the brightness of extended sources in the telescope and explains why so many objects invisible to the eye are visible in the telescope.

This result is astounding! The telescope does not make the image brighter, it only presents a larger image of equal brightness — which the eye then perceives as brighter. If your eye were not more sensitive to large feeble stimuli than to small ones, you couldn't observe deep-sky objects that your unaided eye couldn't see.

There are some other related effects worth mentioning. First, celestial objects such as the North America Nebula in Cygnus — about 1° in diameter — are already fairly large as viewed by the unaided eye. As a result, there is only a modest visual threshold advantage to be gained by using a telescope to view them. Indeed, the North America Nebula may best be seen with low-power binoculars operating at the normal magnification. Large extended objects, those already larger than 5° (such as the Milky Way), simply don't appear much brighter in a telescope no matter what the aperture.

Second, bright objects such as the Moon emit enough light to stimulate cone (or daytime) vision in your eye. The night glass effect applies only to rod (or night) vision. Bright objects, like large ones, will also appear no brighter in the telescope. (This may seem surprising in the case of the Moon, which is almost painfully "bright" in the telescope. The glare and pain, however, are due to the fact that the Moon's image is covering a large part of the retina, saturating your vision. In fact, the surface brightness of the Moon's image is no brighter than the directly observed Moon.) This also explains why terrestrial objects viewed in the daytime appear no brighter in the telescope.

Third, another interesting effect occurs as you increase the magnification. We know the visual luminance threshold drops until the image size reaches about 5°. If the object is small enough, its image size cannot be increased to the optimum size of 5° at powers less than the normal magnification. In this case, it is not possible to attain the minimum threshold luminance before the luminance of the object begins to decrease.

For a telescope of given aperture, then, there is a lower limit to the size of an object which can be viewed with both the maximum image luminance and the minimum threshold luminance. This *night glass limit* can be computed by dividing the normal magnification of the telescope being used by 5° (or equivalently, by 300 minutes of arc). The night glass limit has been computed for the more common aperture sizes and is listed in Table 1.

Any object equal to or larger in angular diameter than the night glass limit of a telescope can be viewed in that telescope under conditions of maximum image luminance and minimum visual threshold luminance. Any image viewed under these conditions cannot be made to appear brighter in a telescope of any aperture, not even in the 200-inch telescope on Mount Palomar.

If you own or are considering buying a large telescope, don't despair just yet. There are several important advantages in visual brightness to be gained from the larger aperture.

Table 1 Apertures, Magnifications, Limits

Aperture Inches	Diameter Millimeters	Light-Gathering Power	Normal Magnification	Magnitude Gain (m)	Limiting Stellar Magnitude (Visual)	Night Glass Limit*
1.0	25	12	3.5x	2.8	8.8	1.4°
1.4	35 Binoculars	25	5x	3.5	9.5	1°
2.0	50 Binoculars	50	7x	4.3	10.3	43′
2.4	60	81	9x	4.8	10.8	33′
3	76	122	11x	5.2	11.2	27′
4.5	114	256	16x	6.0	12.0	19′
6	152	484	22x	6.8	12.8	14′
8	203	841	29x	7.3	13.3	10′
10	254	1,296	36x	7.8	13.8	8.3′
12.5	328	2,209	47x	8.3	14.3	6.4′
16	406	3,364	58x	8.8	14.8	5.2′
200	5000	510,200	714x	13.1	19.1	0.4′

* Values given in minutes of arc.

Table 2 Formulae on Visual Image Brightness

$$\text{Exit Pupil Diameter} = \left(\frac{\text{Aperture Diameter of Telescope}}{\text{Magnification}}\right)$$

$$\text{Light Gathering Power (LGP)} = \left(\frac{\text{Aperture Diameter of Telescope}}{\text{Maximum Eye Pupil Diameter*}}\right)^2$$

$$\text{Normal Magnification} = \left(\frac{\text{Aperture Diameter of Telescope}}{\text{Maximum Eye Pupil Diameter*}}\right)$$

$$\text{Magnitude Gain (m)} = (1.09) \times \text{Log}_e(\text{LGP})$$

$$\text{Limiting Stellar Magnitude} = 6 + m$$

$$\text{Night Glass Limit} = \left(\frac{300}{\text{Normal Magnification}}\right) \text{ min. of arc}$$

*Assume 7 mm or 0.28"

First, the larger the aperture, the smaller the night glass limit. This means that there are more and smaller objects that can be viewed under the conditions of maximum image luminance and minimum visual threshold luminance.

Second, every object smaller than the night glass limit of a given telescope will appear brighter in a larger telescope, provided that the object is not intrinsically bright enough to negate the night glass effect (and no deep-sky objects are).

Third, the normal magnification of even a large telescope is rather low. A larger telescope will have a higher normal magnification, resulting in a bigger image, even if not one of higher luminance. You'll be able to see more details with a larger aperture.

Lastly, it is often hard to obtain normal magnification using standard commercial eyepieces. A 6" f/8 telescope, for example, requires an eyepiece with a 55 mm (2.2") focal length in order to obtain the 22x normal magnification. Owners of Richest Field Telescopes (RFTs) are more fortunate, since the shorter focal lengths of RFTs permit lower powers using more reasonable eyepieces. A 6" f/4 RFT requires only a 28 mm eyepiece to obtain the normal magnification. As a result, observers generally operate at powers well above the normal magnification. At any given power above normal magnification, the luminance of an object's image will be greater in a larger telescope than in a smaller one.

So, if you know a friend who expects his large telescope to produce a brighter view of the North America Nebula, tell him that he's in for a disappointing surprise. But don't discourage him; tell him to look at the Whirlpool Galaxy instead, or better yet why don't you tell him that, under the right conditions, his present telescope can produce an image as bright as the 200-inch telescope on Mount Palomar.

Philip Plante is a Systems Design Engineer with Vitro Laboratories. He has been an avid astronomy enthusiast since 1971, especially in the observation of deep-sky objects. His fascination with extended deep-sky objects led to this article.

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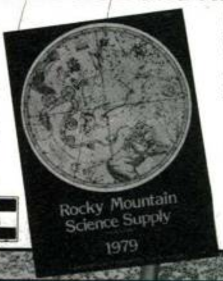

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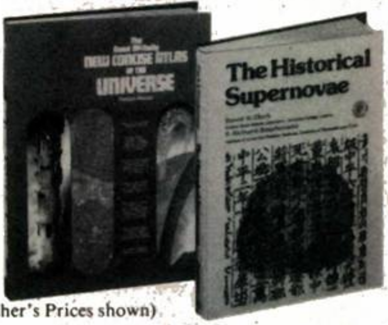

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GAZER'S GAZETTE

Learning to Look

Many beginning observers, confronted with glowing descriptions and color pictures of celestial wonders which seldom square up with their own eyepiece views, end up thinking that their eyes or equipment are poor, or that telescopic observers have vivid imaginations. Chances are neither is true. But it's precisely in the region of unfulfilled expectations that many beginners get turned off from astronomy — often for good.

This disappointment, shared by a surprisingly large number of beginners in astronomy, is totally unnecessary. While there's no short-term cure for inexperience, there are a great many things you can do and be aware of that will increase the amount of appreciation — and pleasure — you get from messing around with a telescope.

Because this initial disappointment is so common, Gazer's Gazette this month is going to say a few things that unfortunately don't often get said to beginners.

What Doesn't Measure Up?

One of the first, and perhaps most important, matters is to forget those glorious and wonderful deep-sky photographs you've seen. Not forever, of course, but at least when you first approach the eyepiece of a telescope.

It sounds bizarre, but it's necessary. Why? Because with a few exceptions like the Sun or Moon, you'll never get a view like the best photos you've seen — even if you had your own 200″ telescope.

Simply put, photography can store up light during many hours of exposure and thus reveal faint details your eye can't see. The eye stores light for only about a tenth of a second before the image is transmitted to the brain. Now your retina is pretty sensitive (in fact it's a lot more efficient than film), but there are limits, and no amount of dark-adaption (more about this later) can produce results like a piece of film.

But before you toss out your eyepieces in despair and consign the mirror to shaving purposes, give plain, old-fashioned looking another chance. Don't expect a TV show in your telescope. Approach the eyepiece with your media-dulled senses turned on again, and be prepared to spend a little time, energy, and attention. It's all up to you. There's no emcee, commercials, or hype — just the universe, out there.

Get Ready for the Planets

You'll never get a rabid astrophotographer to admit this, but telescopes are useful for something other than being attached to the front ends of cameras. The same attribute of film that makes it superior for collecting light from dim objects is its downfall when it comes to lunar and planetary observing.

Sounds crazy, but film really isn't as almighty as you're led to believe. The difficulty with photographing details on planetary surfaces is the turbulence of our atmosphere. Every exposure takes time — even with fast film — and especially when you're using eyepiece projection to magnify the image greatly. During the exposure, the seeing (the amount of turbulence in the air) will move and blur the image.

Your eye seizes its advantage here. You sit there at the scope watching the Moon, say, and as the moments of superb seeing come and go, you catch unbelievably sharp glimpses of craters, rilles, mountains, etc. In the middle 1960s, as part of their lunar mapping program, the USAF attached a movie camera to Lowell Observatory's 24″ refractor hoping to get photos of "eyeball" resolution. The results showed chiefly how valuable experienced visual observations were.

Dramatic Descriptions?

Now no one's going to try and tell you that visual observations reign over all. They don't. But it's important to remember that every instrument used with a telescope, be it photometer, camera or eyeball, will record different things. In most cases, the overlap will be minimal. Tailor your expectations to the equipment you have and *don't look at visual observations as failed photography.*

All right, all right, you say, but how about those grand descriptions...what gives? Well, if truth be told, they are overblown at times. But not so often as you may think.

For one thing, few people today get a really good look at truly dark skies. Many descriptions in print date back to the last century when average skies were far less lit by artificial lights (though they suffered worse than we do from sooty air pollution). Moreover, you shouldn't expect to see everything in your first glance or two through the scope. If you're new to stargazing, you'll need a number of unhurried, leisurely observing sessions to develop your skills. The key here is to take your time, build your confidence, and above all, relax. Remember, it's fun!

Experience Counts...

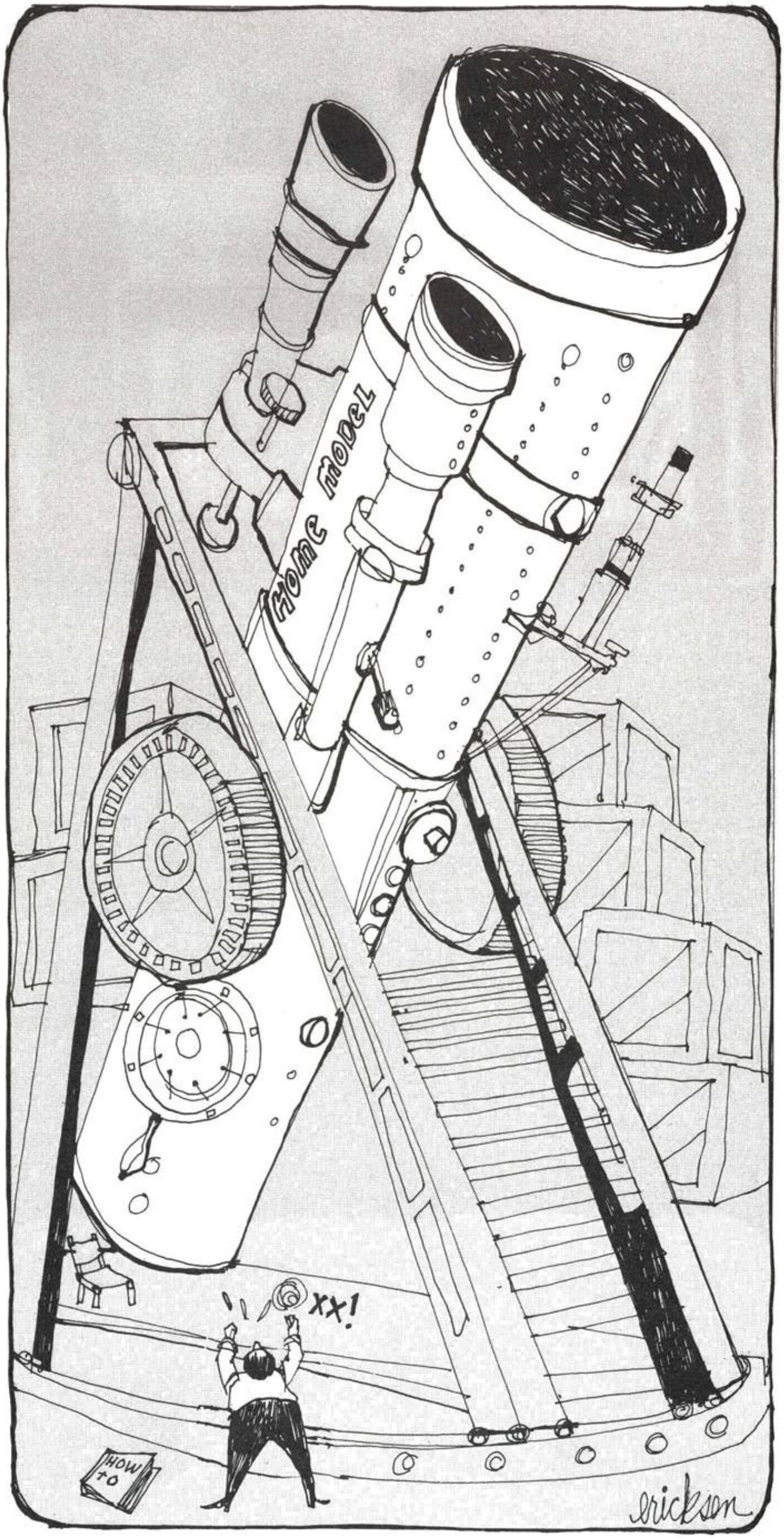
We've said a lot here about expectations; experience is also very important. Experienced observers simply see more, all else being equal, than inexperienced ones do. You can prove this to yourself during the fall and winter with Jupiter. Start watching it now and sketch what you see (belts, markings, etc.). Keep it up over the winter — make lots of sketches. Try to put in a good 20 minutes (minimum!) looking at each session. About next March, haul out your earliest drawings and compare them with your most recent ones. You'll be staggered by the improvement in your ability to see what was there all along.

Precisely the same thing happens when you begin to observe nebulae, galaxies, and dim, distant clusters regularly. And if you're still flinty-eyed suspicious (and who wouldn't be) that other observers' imaginations have advanced inflammation of the sensibilities, then don't read the descriptions they provide — just keep observing and note what you see. You'll wind up surprising yourself, for the descriptions are far less overimaginative than you'd believe now.

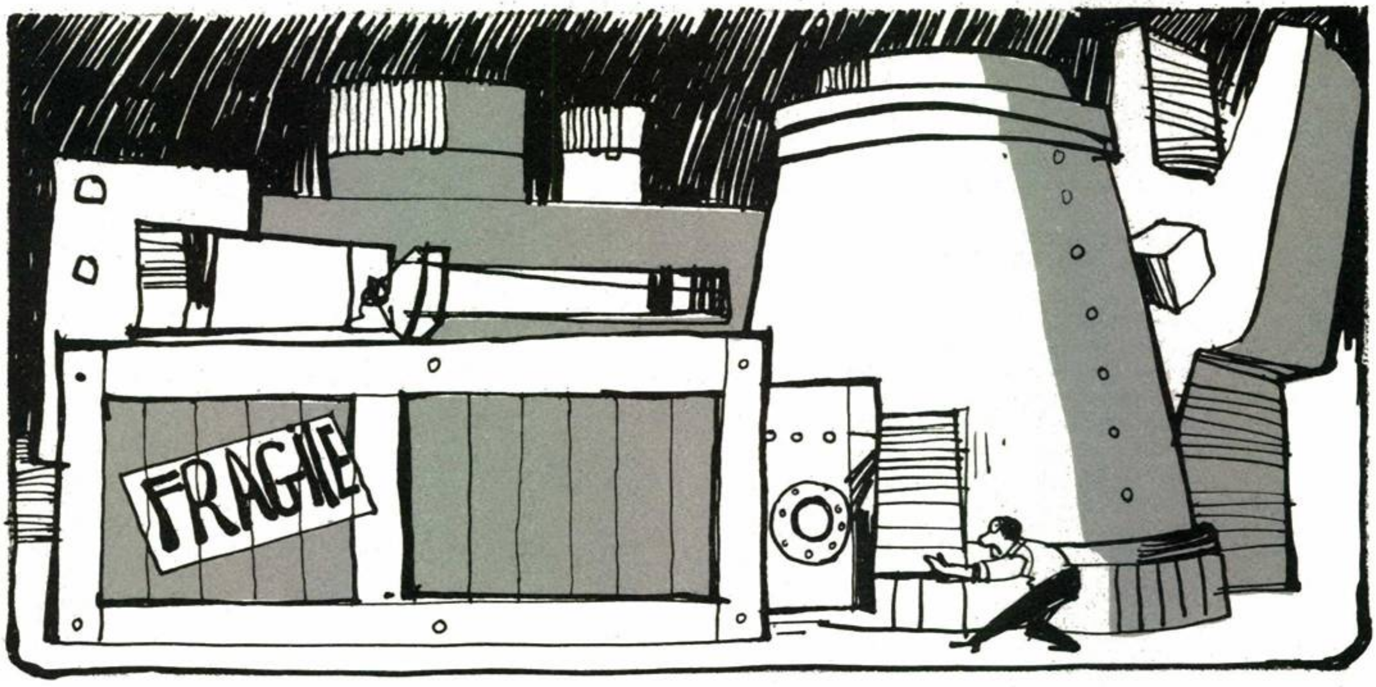
Getting the Most from Your Eyes

The other side of the coin is learning to make the most of your eyes' abilities. Their remarkable ability to adapt to a tremendous range in brightness is, in some respects, their chief advantage. The daytime sky is about a 100 million times brighter than the average nighttime sky, yet your eyes function under both.

In part the eye's adaptive changes are physical and in part they're physiological. The physical part is controlled by the iris, which opens from a fully closed size of about 2 mm up to about 7 to 8 mm (less in older people). Just like the diaphragm of a camera lens (which was of course modeled on it), the iris helps control how much light enters the eye.



The physiological changes are more complex. At low light levels, your retina contains amounts of visual pigments ("visual purple") which bleach out as the light levels increase, thus decreasing the eye's sensitivity. The pigment changes can't handle all the adaptation, however, for the range is too great. So instead, when light levels decrease, your brain begins to amplify the signals from the retina, after the pigmental changes have



happened. About 30 minutes after you're in darkness, the process is essentially complete and you've become fully dark-adapted.

When you go outside to observe, give your eyes time to adjust. You can use those minutes to let the worries of the day ooze away. Perhaps you can start off with gazing at a few old friends — Mizar, Albireo, or maybe one of the planets. You'll do best when your eyes are rested and at ease, and your body is relaxed and comfortable.

In fact, personal comfort can be critical because when you feel rested (and in winter, warm) you can put more effort and enjoyment into seeing. Doggedly hanging in there when you're pooped isn't sensible and doesn't work.

Of course, when you're set up and underway, from time to time you'll want to consult maps or make a note in your logbook. The way to keep from fumbling through your equipment and still save your adaption is to take an ordinary flashlight with you, having first covered the lens with several layers of red tissue paper. This dim red light will save your night-adjusted eyesight.

Another very useful trick you might not know of is a simple trick called averted vision. Your retina is more sensitive in areas that lie to the side of that used when looking directly at something. To take advantage of this, look slightly to one side of the object — catching it out of the corner of your eye, so to speak.

This'll feel kind of strange to start with, since you'll find that you keep looking back directly at the object. But with practice the technique becomes so automatic you won't even be aware you're doing it.

...and Streetlights (ugh!)

Everyone wants a dark sky at their observing site, but few observers manage it easily. Good sites mean long car trips if you live near a big city, and many people end up settling for a quasi-dark suburban site. These can be rather good, but often you must contend with someone's porch light or a streetlight.

In a situation like this, find some way to screen you and your telescope from the light. Buy a rubber eyepiece shade (a small device that fits over the eyepiece to block out stray light) or drape about a square yard of dark cloth over your head. You may even have the cloth around the house already.

The drawback to the eyepiece shade is that you have to get your face in contact with it for the shade to work well — and this will set any scope on a wobbly mount jiggling for several moments. The cloth touches the scope also, but because it's flexible, the disturbance to the scope is less.

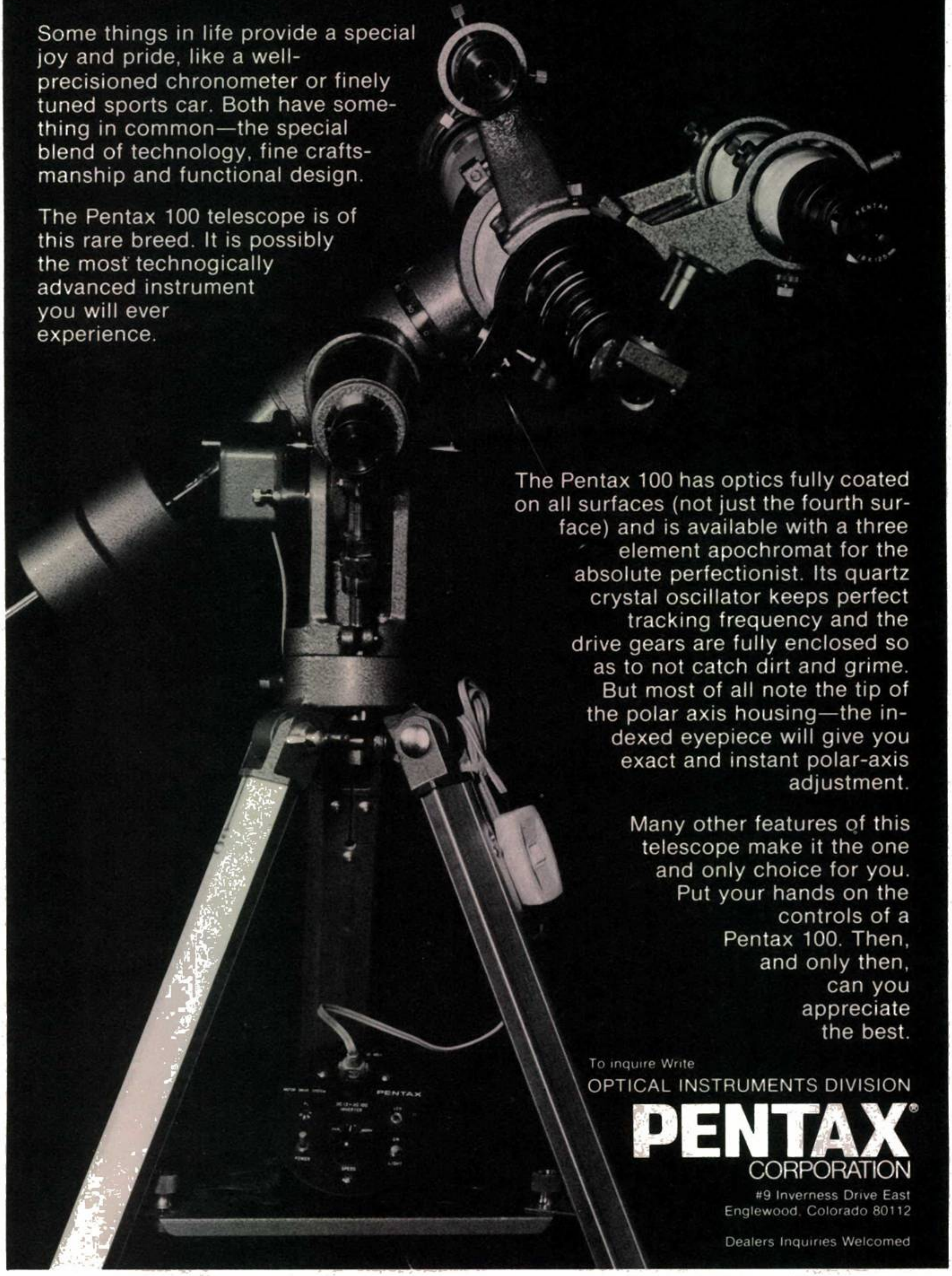
If only one light is bothering you, try placing your scope where a tree, utility pole, corner of the house, or what-have-you blocks off the offending light.

So Keep On Trying

The techniques of observing can seem vast and formidable. If you're a neophyte, you might feel you'll never master it. Yet all it comes down to is experience — which simply means you come back to the eyepiece again and again. It means that Saturn doesn't have to put on a vaudeville act for you to appreciate it, that the Orion Nebula doesn't have to flash neon at you. It means you've learned to put a little effort into the art of looking.

But there's a first look for everyone, and it's nice to know that you never have to be superproficient to enjoy yourself with a telescope and the stars.

— Robert Burnham



Some things in life provide a special joy and pride, like a well-precisioned chronometer or finely tuned sports car. Both have something in common—the special blend of technology, fine craftsmanship and functional design.

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Stars and Nebulas

by William Kaufmann III

197 pages, hardbound, $13.00*
W.H. Freeman and Co. (1978)

According to the publishers, **Stars and Nebulas** is meant for the general public and is a potpourri of information about stars and nebulae. Kaufmann manages to cover nicely the basic topics which are needed in an introductory astronomy course on stars and nebulae. The book could effectively be used in a one-quarter course for college students, provided you don't want to deal with the solar system or extragalactic astronomy.

But as far as being suitable for the general public ... well, maybe not. The lay reader will be pleased at the lack of equations, but will be put off by jargon like "electron degeneracy," "radiative equilibrium," "Hertzsprung-Russell diagrams," and so on. Although Kaufmann does a good job in explaining these terms, and many others like them, there are limits to what he can include in a book aimed at the general public. On the whole, I feel the average lay person doesn't have enough of the physics (which Kaufmann takes for granted) to understand the material presented in this book.

Kaufmann starts with a chapter entitled "A Stellar Scenario," written in poetic prose intended to stimulate the reader's imagination — an interesting and useful approach. He drops into this vein from time to time but somewhat inconsistently, with the result that throughout the text, we find these little excursions mixed with the basics. You get the sense that the book is an abstracted version of a textbook and was produced against a deadline. This seems particularly evident when you notice that not all the diagrams and photographs are referred to in the text. They appear to have been added in haste.

It may be Kaufmann's editor's fault, but there are a number of disturbing sentence structures and poor usages. The term "faint-appearing star" isn't very clear, nor can a statement like "almost everything we know about the universe beyond earth come to us through light" be taken literally, since radio and other non-optical astronomies have also contributed greatly. This is misleading in a book for the general public.

"Our Sun — A Typical Star" presents the usual stuff about the Sun, but we aren't told why it's a typical star, nor that it isn't even really typical since most stars are dwarfs. There are chapters covering the birth, maturity, old age, and death of stars, and he gives a nice summary of stellar evolution. But here again "degeneracies," "equilibriums," and "turbulences" obstruct the path of the layman.

Kaufmann is particularly interested in black holes, so he naturally works up to them as a climax: "Black Holes in Space-Time." In referring to the nature of Cyg X-1, the chapter and the book suddenly ends with a sentence that reads "The only remaining alternative is a black hole." You're left sitting there, high and dry, wondering what next? There is an epilogue meant to round things out a little, but it doesn't succeed very well.

Taken as an attempt to get a reasonably priced, simple text on the market, **Stars and Nebulas** is rather good. It contains 8 color photos (the usual standard ones seen everywhere), yet the paperback edition costs only $7.00.

Overall the book seems to have originated as a typical astronomy text that was chopped into three pieces, to be published as a trilogy. It probably won't be suitable for a mass market, but it may well be used in some colleges where a cheaper, if somewhat superficial, book is needed. *Gerrit L. Verschuur.*

**Also available in paperback for $7.00.*

◆

Astrophoto Biennial 77-78

edited and produced by John R. Sanford

105 pages, softcover, $8.00 ppd. from:
Orange County Astronomers (1978)
2215 Martha Avenue
Orange, CA 92667

In 96 photographs and three short articles, John Sanford brings you face-to-face with the current state of black and white celestial photography. This book is a collection of the work of 22 astrophotographers, many of them West Coast. Most of the pictures are deep-sky, but five Saturns, several Jupiters, comets, and the Moon add variety. Though rounded out with three articles that deal with professional astrophotography (CCDs — a "solid state TV camera," Kowal's search for Chiron, and a roundup of techniques for hypersensitizing films), the bulk of the book is the picture collection. It is a well-designed publication, printed on heavy paper, handsome in appearance, and well-produced despite printing problems that cause tiny streaks in some of the pictures.

Striking, in this collection, is the opportunity to compare the same object as photographed with differing equipment and photographer, for there are four images of M-51, four of M-33, no less than five of Saturn, and three each of the Lagoon, NGC-253, and M-13. Graininess, image scale, guiding, and enlarging all play crucial roles in the successful presentation of a celestial object — yet the beauty inherent in the Whirlpool comes through with every image presented!

On the other hand, one *does* wonder at the limited range; in addition to those already mentioned, M-81, M-101, the Horsehead, the Rosette, M-16, and several others are also presented more than once. The reader soon appreciates those astrophotographers who seek out new subject matter: IC 1396, Sharpless 296, NGC-6888, IC 1805 and 1948, and IC 5067, for example, rather than the tried and true Messier list objects. Perhaps the very existence of this volume will spur others to search out fresh nebulae and apply their skills to them.

Most impressive to me were Brownlee's photographs of galaxies with a 16-inch reflector, Jack Child's photograph of the fascinating object NGC-7023, Ronald Royer's beautiful rendition of the Coal Sack and a field in Cygnus, E. Ken Owen's stunning Saturn, and Howard Zeh's very detailed study of the crater Copernicus. John Sanford must be congratulated for pooling the talent of so many fine astrophotographers and successfully creating a beautiful book. Let's hope, though, that he will push them into exploring a wider range of subject matter should he contemplate another astrophotography biennial. *Richard Berry.*

NEW BOOKS

The Discovery of Neptune
by Morton Grosser
172 pages, paperback, $3.00
Dover Press (1979)

The discovery of Neptune in 1846 was a grand triumph for mathematical astronomy; it also touched off a very acrimonious scandal in British astronomical circles. Grosser's book is about how the discovery was made and the equally fascinating interactions of the personalities involved. While the priority squabble after the discovery got pretty underhanded at times, the principals in the action (Adams and Leverrier) stayed far above it all, remaining good friends. It's an enjoyable story.

Megalithic Remains in Britain and Brittany
by A. Thom and A.S. Thom
192 pages, hardcover, $23.50
Oxford University Press (1979)

In the field of archaeoastronomy, the Thoms (a father and son team) have considerable renown. Singly and together they have been at work investigating prehistoric stone circles (known as cromlechs) for several decades. In this book they describe the alignments and their probable astronomical uses at a number of sites in Britain and Brittany. The book's reader is assumed to be familiar with some astronomical knowledge, but the authors include explanations where they're needed most.

New Horizons in Astronomy
by John C. Brandt and Stephen P. Maran
614 pages (illus.), hardcover, $16.50
W.H. Freeman (1979)

This is the second edition of Brandt and Maran's book, the first edition appearing in 1972. The authors present the subject in the "classical" manner: they start with primitive (non-telescopic) astronomy and progress through the solar system out to the stars and galaxies. The equations used are minimal, as fits the non-science student audience the book is aimed at.

Galaxies: Structure and Evolution
by R.J. Tayler
203 pages, hardcover, $21.00
Crane, Russak (1979)

Galactic astronomy is a field in which the books need to be updated constantly. Yet behind all the frantic revisions that happen now and again, there stands a core of basic knowledge about materials and processes. Tayler's book is designed to give its reader just that background in the subject. He concentrates heavily on studies of our Galaxy, because it's the closest to hand and best known. The level of presentation assumes a knowledge of some physics and mathematics.

Natural and Artificial Satellite Motion
edited by Paul E. Nacozy and Sylvio Ferraz-Mello
434 pages, hardcover, $24.95
University of Texas Press (1979)

In December 1977, the National Science Foundation sponsored a conference on satellite motions. This book is the record of the papers given at the conference. Most of the text is highly mathematical, but if you see a copy of the book, read through the first part on observations of natural satellites. You'll get a good view of where we now stand and what difficulties are involved in this work.

Foundations of Astronomy
by Richard Knox
184 pages, hardcover, $10.95
John Wiley (1979)

The scope and content of modern astronomy are surveyed for the interested layman in this book by an experienced British amateur astronomer and science writer.

Mysterious Universe: a handbook of astronomical anomalies
compiled by William R. Corliss
710 pages, hardcover, $15.95
Sourcebook Project (1979)
[Order from Sourcebook Project, Box 107
Glen Arm, MD 21057]

In 16 chapters organized by subject, Corliss has assembled a great number of astronomical reports having "anomalous" data. The original published sources are chiefly scientific journals, both technical and semi-popular. Many of the accounts go back decades or more. The contemporary reader (with 20/20 hindsight) gets an intiguing overview of past (and some present) scientific problems, but because the emphasis is on the mysterious, no explanations are given even when the phenomena are now understood.

Mars
by Percival Lowell
228 pages, hardcover, $16.50
History of Astronomy Reprints (1978)
[Order from P.A. Luther, Box 262,
Bernardston, MA 01337]

In 1895, Percival Lowell published the first of his three famous books about Mars. Long out-of-print and fetching high prices in the antiquarian book market, **Mars** has been republished in a photo-offset facsimile edition. Lowell's theories about the habitability of Mars haven't endured, to say the least, but the book still has a real attraction for planetary observers. Lowell took great pains to describe fully his careful observations and there are numerous reproductions of his sketches.

Megaliths and Masterminds
by Peter Lancaster Brown
246 pages, hardcover, $14.95
Scribner's (1979)

Mr. Brown's book surveys the varied and sometimes ingenious theories that have been concocted to explain Stonehenge and the many other arrays of standing stones in Great Britain and northwestern France. The book's dominant theme is how the archaeologists have been slowly, and often unwillingly, compelled to adopt an astronomical interpretation. In an area that has been rife with sloppy thinking and analysis, he's careful to differentiate plausible speculation from rampant nuttiness.

Architecture of the Universe
by Necia H. Apfel and J. Allen Hynek
499 pages (illus.), paperback, $12.95
Benjamin/Cummings (1979)

In 1972 these two authors brought out an astronomy textbook for non-science majors. This current book is the revised version of the earlier text. The amount of mathematics is minimal, and the approach used in the original edition — cosmic scene-setting first, then back to the fundamentals — has been preserved, thus capturing the reader's interest early on.

Projects and Demonstrations in Astronomy
by Donald Tattersfield
331 pages, hardcover, $27.50
John Wiley (1979)

With the great number of people taking introductory courses in astronomy, many instructors long for good collections of experiments and projects that can give a sense of what astronomers do and how they go about it. This book has a large number of projects (61) and many sections on various topics. More remarkable is the number of stellar and galactic astronomy projects; many books of "lab projects" spend a great deal of time on experiments that bear little relation to current astronomical work.

Saturn and Beyond

by Isaac Asimov

222 pages, hardcover, $7.95
Lothrop, Lee & Shepard (1979)

Asimov's at it again, this time with a book for the general reader about the planets from Saturn on out. As usual the approach is breezy, yet there *is* a good deal of information here, including some 68 tables in the text. If you're interested in the outer planets and have kept up with scientists' findings, you won't likely find a lot new in it, but much of the book would interest the beginner.

Life on Mars

by David Chandler

212 pages (illus.), hardcover, $9.95
Dutton (1979)

Chandler examines the question of Life On Mars from the viewpoint of the Viking mission. He describes how life arose on Earth and the possibilities of it occurring elsewhere in the universe. Choosing Mars as the most promising place in the solar system, he goes on to suggest rather strongly that life *does* exist there, despite considerable (albeit ambiguous) scientific evidence to the contrary.

Pictorial Guide to the Moon

by Dinsmore Alter, revised by Joseph H. Jackson

216 pages (illus.), paperback, $6.95
Thos. Crowell (1979)

Now in its third edition, this popular photobook on the Moon was first issued in 1963. About a third to a half of the photos in the book are from spacecraft, the remainder taken from Earth. The emphasis is on the appearance of lunar features and what they tell us.

Star Atlas

edited by Jacqueline and Simon Mitton

32 pages (illus.), paperback, $1.95
Crown (1979)

The star atlas that appeared in the *Cambridge Encyclopaedia of Astronomy* is now available as a separate booklet. Apart from the star charts (which go down to magnitude 6.5), the **Atlas** has an introduction to explain how to use the charts and to tell something about the objects therein.

Introduction to Experimental Astronomy

by Roger B. Culver

195 pages, paperback, $7.50
W.H. Freeman (1979)

Strongly resembling a workbook (the pages are even perforated for removal), this book contains a number of lab projects for introductory astronomy courses. There are 22 experiments arranged to put simple physical ones (determination of the velocity of light) first and winding up with a determination of the Hubble constant and observations on a quasar.

Great Ideas and Theories of Modern Cosmology

by Jagit Singh

416 pages, paperback, $4.50
Dover (1979)

The history of astronomy contains many theories of cosmology, but only since the discovery of the scale of the universe, roughly a half-century ago, have the theories been grounded in astrophysics. Singh's book, revised and expanded from the 1961 edition, surveys the most important of these theories and traces their development, ending up with a summary of where we now stand.

Exploring the Universe

by W.M. Protheroe *et al.*

432 pages (illus.), hardcover, no price given
Charles E. Merrill (1979)

Working on what's called the "classic approach" (history of astronomy, then solar system, and finally cosmology), the three authors of this introductory text for non-science majors present a clean-looking and attractive book that covers the subject well. Most of the illustrations are black and white, but there are 42 color plates as well.

The Future United States Space Program

edited by Richard S. Johnson *et al.*

2 vols., 841 pages, hardcover,
$40 each volume, $80 per set
American Astronautical Society (1979)

These two books are the record of the AAS conference held October-November 1978. As there were 18 sessions with several papers per session, the amount of information contained here is large. The subjects covered ranged over guidance, economics, medicine, engineering and space science, to name a few. Most of the papers are aimed at the professional, but the volumes are worth at least a library trip to look through if you care about where the space program is going.

Astronomy

by Terry Moloney

96 pages, paperback, $3.50 approx.
Macdonald Educational (1977)
[address: Holywell House, Worship St.,
London EC2A 2EN, England]

This little book covers a lot of ground for an introduction to the subject. Divided into three sections — information, activities, and reference — it covers the basic facts in the first part, tells you how to make simple astrophotographs, construct a telescope, and build an observatory in the second, and provides a cut-out planisphere, booklist, Moon map, and table of bright stars and principal constellations in the third section.

Astronomy: an introduction for the amateur astronomer

by Jacqueline Mitton

142 pages, hardcover, $7.95
Scribner's (1979)

Amateur astronomers having some slight background in astronomy will find this book useful as an introductory overview of the subject in more depth than usual. There is a small amount of mathematics and the illustrations are well-chosen and reproduced.

Astronomy with Binoculars

by James Muirden

156 pages, hardcover, $8.95
Thos. Crowell (1979)

Binocular observing has gained tremendously in popularity over the last few years, perhaps because a pair can be found in many households. And for some people, binoculars are as sophisticated an astronomical instrument as they want to have. The first edition of this book appeared in England in 1963, and was re-issued there in an updated edition in 1976. This edition has been slightly revised (to give a more North American bias) from the 1976 edition, and is a good choice for the person interested in getting the most observational value from their binoculars.

Stars and Clusters

by Cecilia Payne-Gaposchkin

262 pages (illus.) hardcover, $22.50
Harvard Univ. Press (1979)

Throughout the 1950s and 60s, Mrs. Payne-Gaposchkin's *Stars in the Making* was one of the best popular level books on general stellar astronomy. This book (like the previous one, it's part of the Harvard Books on Astronomy series) brings the story up to date. There are some finely reproduced photographs and many diagrams. The intended reader is the interested layman.

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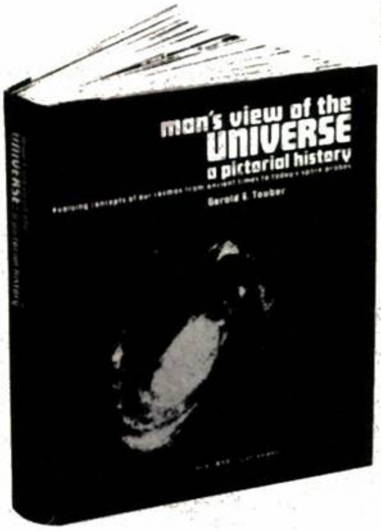

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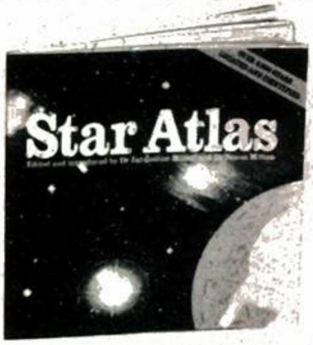

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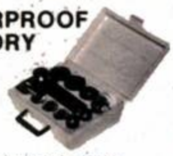

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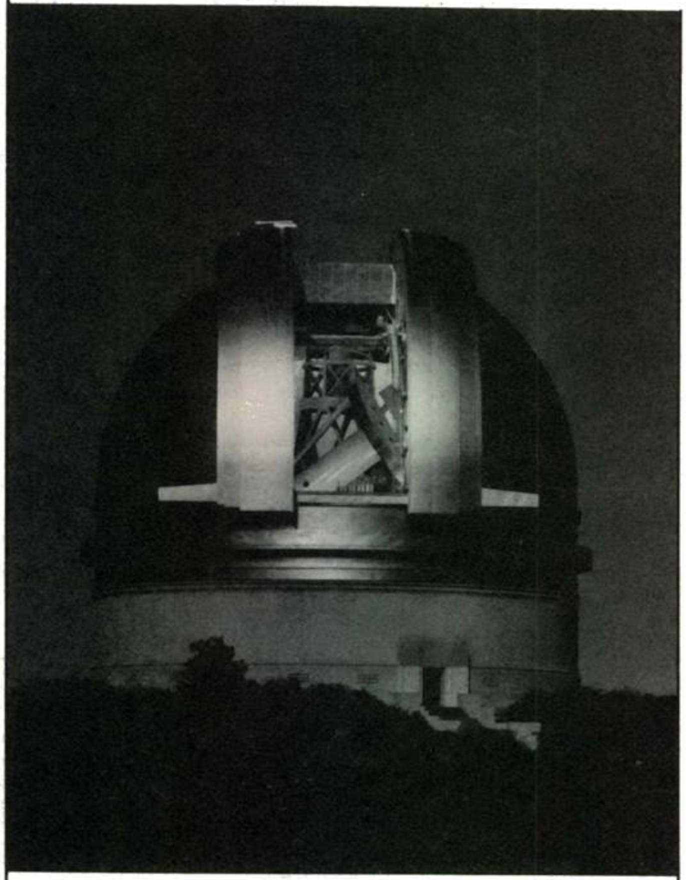
A Giant Celebrates a Birthday



This year marks the 30th anniversary of the first use of one of the premier scientific instruments of all time — the giant 200-inch Hale telescope at Palomar Mountain. Since 1949, at every opportunity, the shutters on the massive dome have slid open to the night sky, and the 500-ton telescope has captured and recorded light from stars millions of times fainter than can be seen by the unaided eye. Both technological progress and the brilliant engineering that first went into its construction have kept the instrument one of the most important in astronomy.

Astronomers using the Hale telescope have contributed enormously to the understanding of the universe, and a complete listing of the advances due to the instrument would be voluminous. Such studies, which could only have been done with the 200-inch telescope, include:

- The determination to great distances of the Hubble constant, the measure of the rate at which the universe is expanding;
- Studies of the rate at which that expansion is slowing;
- Studies of star clusters, which made possible an understanding of how stars evolve; and
- Discovery of quasars and the first determinations of their red shift.

"We have found that those parts of the instrument that one is bound to — the basic structure of the telescope — are really superb," says Maarten Schmidt, director of the Hale Observatories, which is run by Caltech jointly with the Carnegie Institution of Washington. Schmidt is the astronomer responsible for the discovery of the large red shift in the light from quasars, which indicated that they are the most distant objects in the universe. "The 200-inch is as good as telescopes that were built only recently," he says.

A visit to Palomar Mountain reveals how lightly three decades of almost constant use have touched the telescope. The massive gears that allow the giant to track the slow movement of the stars across the sky each night are as unmarred as the day they were installed, and spare gears still hang on the wall where they were placed decades ago. The 1,000-ton dome rotates with a silky smoothness, emitting only a faint hiss and a delicate squeak as it moves.

"The instrument is in excellent shape," says Gary Tuton, superintendent of the five telescopes on Palomar Mountain, which also include 18, 20, 48, and 60-inch telescopes used in various research modes. "The amount of down-time for this mass of equipment is quite minimal, and can only be attributed to the genius of the designers."

Maintenance of the big telescope includes washing the mirror with distilled water and then drying it with soft towels four times a year, and realuminizing the mirror about once every three years.

The telescope is named after George Ellery Hale, the prominent astronomer and master fund-raiser who persuaded the Rockefeller Foundation to finance its construction, to the tune of $7 million.

The construction of the telescope, which one science magazine described later as "a kind of overachievement for its time, an astronomical *tour de force*," was fraught with adventure and peril. The huge mirror was made from Pyrex, after experiments with fused quartz failed. The blank was successfully poured on the second try; the first attempt failed when weight-reducing cores broke loose and bobbed to the surface of the molten glass. After its pouring, the disk was menaced, not once but twice, by rising floodwaters of the Chemung River, which ran beside the Corning Glass Works in Pennsylvania where the disk was poured. At one point, workmen pulled the disk clear only hours before the river inundated the spot where it had rested.

Once safely in the workshop at Caltech in Pasadena, the disk was ground by a team of technicians who removed 5¼ tons of glass from the 20-ton blank, bit by laborious bit over four years.

Active construction began at Palomar in 1935, was interrupted by World War II, and continued at the end of hostilities to completion in 1948. The first pictures with the finished telescope were taken in December 1949.

Besides its immense scientific contributions, the 200-inch telescope has served over the years as an inspiration for

Index

- A Giant Celebrates a Birthday
- Quasar Question: One or Two?
- Martian Oases
- A Cratered Earth
- A Galactic Corona
- Death of the Dinosaurs
- More Black Holes?
- The Lunar Treaty

later instruments. "I believe the fact that one could build a successful 200-inch telescope made it possible for other groups to plan large telescopes without hesitation," says Maarten Schmidt.

The 200-inch has even produced nationalistic envy — as evidenced by the Soviet 236-inch telescope. "This telescope, which has not proven to be a particularly successful scientific instrument, was exclusively a matter of national pride," Schmidt says. "The Soviets use the metric system, and one cannot help but notice that their 236-inch (or six meter) telescope is precisely one meter larger than our 200-inch (that is, approximately five meter) Hale Telescope."

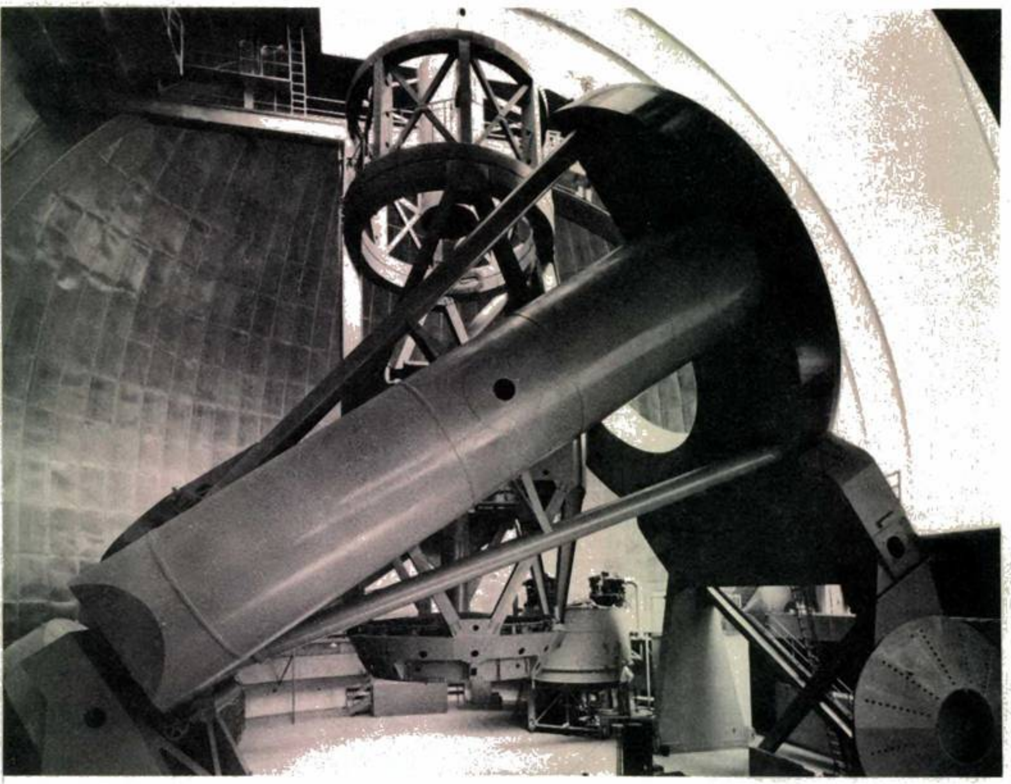
The 200-inch telescope's place in astronomy today is as solid as its construction, one reason being its continuing modernization. When the telescope was built, photographic plates were the predominant data-recording method. Photographic plates can record enormous amounts of data, but they have their drawbacks. Hundreds of photons of light are required to activate a single grain on a photographic plate, so that, for very faint objects, exposure times can range up to several nights. However, even if long exposures can be accomplished, photographic plates are nonlinear in their response; twice the exposure does not result in twice the number of grains being activated. Also, the plates become saturated after too long an exposure.

Since the mid-1960s, scientists at Hale Observatories and Caltech have applied numerous sophisticated electronic devices to overcome those limitations. Electronic detectors can record far more sensitively, so that objects which formerly required hours of exposure, now require only minutes. Whereas photographic plates are only about 2% efficient in terms of the translation of photons of light into a signal, most current electronic detectors can reach about 25% efficiency, and increases to 80% have been achieved with new imaging systems based on charge-coupled devices.

Even with the enormous advances in astronomy over the last three decades, Hale Observatories astronomers expect the Hale telescope to continue as an important scientific instrument.

"Astronomy is data-limited," says Schmidt, "which means that if you doubled the number of telescopes of 100 inches or so, I think the output of astronomy would almost double, because there is so much to be asked of the universe."

Technology will no doubt continue to advance the science of astronomy, but the giant telescope at Palomar will remain a pre-eminent scientific instrument. And perhaps just as importantly, it will continue as a reminder of what daring scientist-entrepreneurs like George Ellery Hale and his team of gifted colleagues can do for science.



The huge 200-inch Hale telescope on Mount Palomar is seen above aimed at the zenith. Photographs courtesy of Hale Observatories.

Quasar Question: One or Two?

The mysterious quasars, or quasi-stellar objects, have puzzled astronomers and astrophysicists for over 15 years. With their enormous red shifts, quasars seemingly lie far out toward the very edge of the observable universe, although some, notably Halton Arp of the Hale Observatories, are convinced they are relatively nearby objects whose red shift must be explained in other ways.

The issue has been raised again in connection with the discovery of a quasar whose image may have been split in two by the presence of an extremely massive object along our line of sight. Writing in the May 31 issue of *Nature*, Dennis Walsh of the Jodrell Bank Radio Astronomy Observatory, Robert F. Carswell of Cambridge University's Institute of Astronomy, and Ray J. Weymann of the University of Arizona's Steward Observatory reported that the two objects designated 0957+561 A and B, separated by only 5.7 seconds of arc, appear to be either a never-before-observed example of identical twin quasars — or a single quasar whose light has been refracted by a gravitational lens so that a double image is seen.

The gravitational lens effect is an immediate consequence of Einstein's General Theory of Relativity, which predicts the curvature of light paths along the geodesics of distorted space-time near massive objects. This curvature of light has been detected a number of times, most notably in the famous 1919 solar eclipse experiment. But the actual focusing of light rays to form an image, as though they had passed through a lens, has never been observed. This "gravitational lens" effect is produced only when the mass involved is particularly great, so that there is a considerable bending of the adjacent space-time. Furthermore, the object so focused must be almost exactly in the line of sight with the massive object. Still, precisely these requirements may have been met in the case of 0957+561 A, B.

A perfect, exact alignment would spread the light of the quasar out into a ring, but a very slight deflection of the focusing mass would result in two separate, somewhat crescent-shaped images being formed. No such crescent shape has yet been observed, both objects appearing as point sources, but a higher resolution might reveal a distortion in the images.

Although the possibility of twin quasars arising from some unique evolutionary process can't yet be dismissed, the researchers lean toward the more exotic explanation of a gravitational lens effect. They point out that spectra taken of the two objects are virtually identical, which would otherwise be surprising since quasar spectra have been observed to vary greatly, and the red shifts of the two objects are exactly the same, indicating that they lie at the

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same distance from us. The authors note that the odds of finding a massive elliptical galaxy (such as M-87) close enough to a quasar's light path to Earth to produce a gravitational lens effect are only one in 100,000, but they also observe that "while such coincidences must be very rare, it is not out of the question that we should have one example" among the approximately 1000 known quasars. No *other* double quasar like 0957+561 A, B has ever been observed.

Subsequent observations of the double quasar carried out by others with the new Multiple Mirror Telescope on Mt. Hopkins in Arizona established the near-identity of spectral characteristics and red shift of the two objects. "These observations," note Walsh, Carswell, and Weymann, "strengthen the case for a gravitational lens."

They calculate that such a lens could be the result of a mass of at least a trillion suns concentrated within a space about 200,000 light-years across. These requirements are fulfilled by a number of known giant elliptical galaxies. Although no such galaxy appears on photographs of the area, this is not surprising since it could easily be too distant to be visible while still lying between us and the more brilliant quasar.

Such a result, however, implies that the quasar itself must indeed lie at enormous, so-called "cosmological" distances, and therefore that its observed red shift is indeed due to its velocity of recession and not to any other cause.

One way of confirming the gravitational lens explanation would be to find light curves identical in shape for the two images, assuming the quasar is indeed variable (as many are). But since the quasar lies at a distance measured in billions of light-years, the slightly different path lengths of light rays producing the two images could result in a time difference between the two light curves of months or even years. Astronomers will be monitoring 0957+561 A, B regularly to look for variability. If the same patterns are found in both, 0957+561 A, B will be established as the only known example of a gravitational lens effect — and those who hold that quasars are indeed extremely distant (and therefore incredibly brilliant) objects will have some very strong evidence in support of their position.

Martian Oases

It was mid-morning of a calm, clear, late-spring day on Mars. The place was the "Lake of the Sun" (Solis Lacus) in the southern equatorial region, latitude 25°S, longitude 85°. Temperatures were already above freezing and would rise to 70° Fahrenheit at noon, after a low of -107° F during the night. What was about to occur that day in 1973 revealed vital clues concerning the existence of two oases of liquid water and the cause of annual global dust storms on the Red Planet.

Dr. Robert Huguenin, currently the director of the Planetary Chemistry Lab at the University of Massachusetts Astronomy department, recently described what he saw that day in 1973. He was using the 88-inch reflector on top of Mauna Kea in Hawaii to obtain detailed spectrophotometric images of Mars to determine the mineral composition of the surface materials. By chance he obtained instead a detailed spectral look at the birth of the global dust storm of 1973.

According to Dr. Huguenin there were two surprises when the data were analyzed: a huge and distinct ring of water vapor appeared suddenly and expanded symmetrically from a small area on Mars. The second surprise was that a dust cloud appeared at the same place (Solis Lacus).

Huguenin had only two days to observe the storm's development. "The Lowell Observatory's Planetary Patrol obtained helpful data during the entire storm. They photographed Mars using blue, green, and red filters giving a day-by-day report on the storm that blotted out the martian disk for over 20 days," reports Huguenin.

The annual dust storms (every two years, Earth-time) have been observed for decades, but were considered a nuisance to Earth-based observers. Until now, even after the Mariner and Viking probes of Mars, the reason for the annual occurrence of the planetwide storms has remained a puzzle.

It became a deeper mystery when the two Viking landers reported only moderate wind velocities, not enough to raise even fine dust high into the thin atmosphere.

Now 6 years and two dust storms later, Huguenin with the help of three associates, has reported important results to the 10th annual meeting of the NASA sponsored Planetary Geology Principal Investigators. The group met this June at Brown University in Providence, Rhode Island.

Huguenin proposes that rapid outgassing of solid and liquid water would not only produce the water vapor ring seen as "blue clouds," but also eject enough dust into the air to absorb heat. The trapped heat would then initiate enough air movement to spread the dust over the planet.

A 1975 report in **Icarus** by W. Johnson, proposed that heated absorbed CO_2 would outgas violently, jetting fine talc-like dust into the air. Since Viking landed it is now known that solid CO_2 exists only in the polar regions, if at all.

"Until recently Mars looked like a very, very dry planet. There just wasn't enough water clinging (adsorbed) to the surface material to produce so much water vapor," explained Dr. Huguenin.

The Viking water vapor map of the mid-latitudes revealed what they were looking for, two anomalous areas that were high in water vapor. The areas, not surprisingly, were Solis Lacus, and another storm birth-area, Noachis Hellespontus. This larger area, 1200 km wide compared to Solis Lacus' 400 km, is located at 30°S latitude, 300° longitude.

The Noachis area had been observed to have ground hazes, fogs, and "blue clouds" during several recent oppositions of Mars. In the storms of 1956 and 1971 (the one that covered Mars at the start of the Mariner 9 photographic mission), this area was the apparent source.

"The Viking thermo-inertia map told us that both areas are in the warmest regions of Mars. It is quite possible that liquid water exists throughout the year, especially if the water is a salt brine," reports Huguenin.

Again the landers revealed that indeed there is salt in the soil samples collected at the two areas. There is a good chance that salt is common in the two oases thus reducing the freezing point of the water by 40° Kelvin.

More than high temperatures and the presence of water is necessary to explain the existence of liquid water. Due to very low air pressure (10 millibars) the heated water should go directly from solid to a gaseous state. Huguenin suggests that the water could be kept liquid by a vapor pressure barrier formed around the melting ice a few centimeters beneath the surface. The top three centimeters of soil would also help maintain a stable, low-level atmosphere that would allow liquid water to exist.

The initial outgassing of the water vapor is irregular, indicating that the salt brine marshes are patches separated by drier areas. According to Huguenin there isn't enough adsorbed water in the form of an ice glaze in the two areas to produce the observed amounts of vapor. Their instruments would have detected any ice glaze thicker than one millimeter.

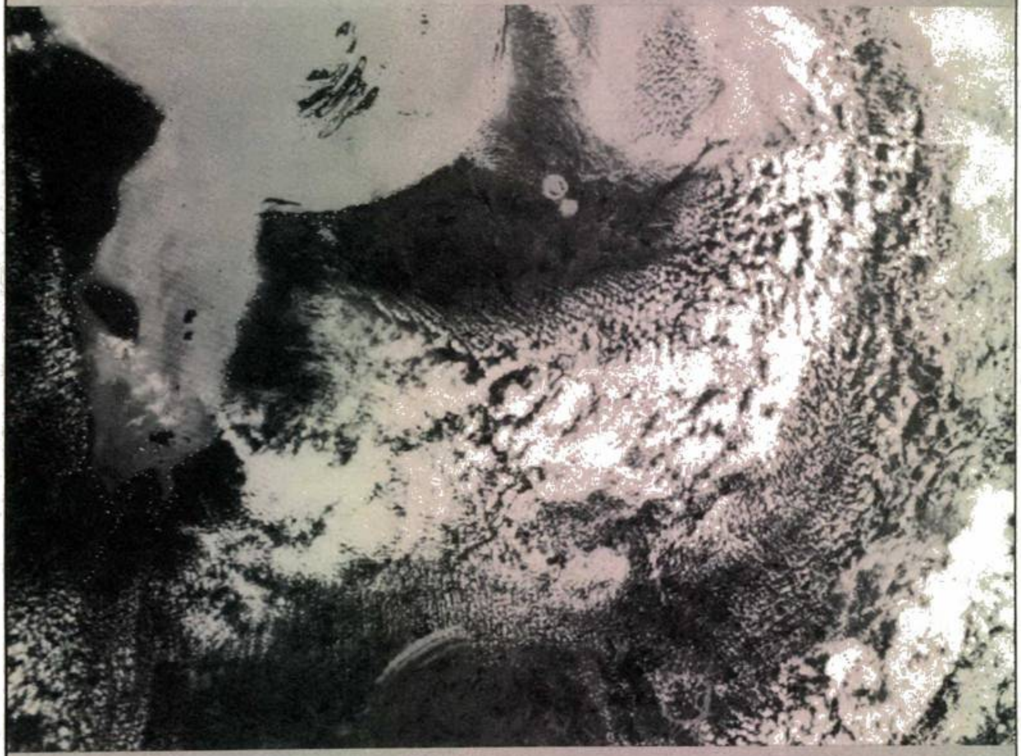
After three to four days the air over the million square kilometers of Solis Lacus is filled with dust up to a one kilometer altitude.

What happens after the oasis is covered by water vapor and dust? "The dust and water vapor increase the temperature of the air at the dense center of the cloud. The warmer air forms a downdraft that pushes the surface dust and vapor out to the periphery of the dust cloud. When the vapor reaches the cooler, clear air it condenses, forming frosts and ground fogs. The water vapor and frosts disappear after a few days but the dust cloud grows and the winds increase," answered Hugueni.

When the storm ends in 20 or more days the water vapor returns to the original source regions. Right now there is no clear picture how this happens.

Can life exist in these oases? Conditions are benign enough to compare with the Sahara desert. The big problem, according to Karen Miller, one of Huguenin's associates, is the ability of microorganisms to adapt and thrive in an environment that freezes and thaws daily.

A Cratered Earth



Jupiter's torn and tortured satellite Io may show no evidence of cratering, but the less volcanically active Earth certainly does! The photograph above, an 11 micron infrared image, was taken by the Tiros-N weather satellite on June 18. It shows the area to the east and southeast of Hudson Bay. Clearly seen are three meteorite impact craters, two just east of the Bay and one in the lower right corner tucked under the cloud. The craters east of Hudson Bay are Clearwater Lake East and Clearwater Lake West, in Quebec. According to the Observer's Handbook, these features are about 300 million years old. The larger has a diameter of 20 miles, while the smaller is 14 miles across. The circular ring in the lower right is Manicouagan, also in Quebec. This crater is a little over 200 million years old, and is 44 miles in diameter. Some geologists believe that the main basin of Hudson Bay itself could be the result of a particularly large meteor impact hundreds of millions of years ago. (Scientists estimate that Io's surface is completely regenerated every 10 million years or less.) Photograph courtesy of the Atmospheric Environment Service of the Canadian Weather Service.

"It was the extreme desiccation (dryness) of the two landers' environments that ruled out the chance for life. Everything else theoretically needed for life was present," said Miller.

The scientists will perform an extensive series of simulations in the Planetary Chemistry Lab. They will study their dust storm model and the ability of some Earth microorganisms to survive Solis Lacus conditions. They'll be duplicating every known condition that exists in the oases except gravity.

Beyond the simulations and remote sensing could be a Viking-type lander at the two oases. "Due to the benign conditions in these areas it is very important that any lander be carefully decontaminated. Hopefully the contamination hasn't already happened," warned Huguenin.

A Galactic Corona

Most celestial objects seem to be surrounded by a halo of gas held in place by their gravitational attraction. Earth has its atmosphere and the Sun its corona.

Now two astronomers have found a cloud of very tenuous, hot gas surrounding our Milky Way Galaxy — a gas cloud similar to the corona which surrounds the Sun. Professor Blair D. Savage and his associate Klass S. de Boer of the University of Wisconsin's Washburn Observatory have said that the galactic corona is a tenuous gas a million times thinner than the best vacuum ever produced on Earth. And even though the amount of gas detected represents less than 1% of the interstellar gas found in the Milky Way, Professor Savage points out that "this discovery has important implications for galactic and extragalactic astronomy." Heated to about 180,000° Fahrenheit, perhaps by exploding stars, the halo most likely rotates with the slowly swirling Milky Way.

Savage and de Boer announced their discovery in the June 1 issue of *Astrophysical Journal.* They said they detected the galactic corona in satellite observations made over the past nine months by the International Ultraviolet Explorer (IUE), a space observatory jointly administered by NASA, the United Kingdom's Space Research Council, and the European Space Agency.

Their announcement marks the first confirmation of a prediction made 23 years ago by Princeton University Professor Lyman Spitzer, Jr. Spitzer had assumed only that such a gaseous halo would be in hydrostatic equilibrium and gravitationally bound to the galaxy. The observed properties of the corona found by Savage and de Boer are in line with Spitzer's calculations.

The discovery of a galactic corona could expand our meager knowledge of what lies between the galaxies and could lead to a better understanding of quasars. The hot corona represents a significant new gaseous region of our Galaxy. Interstellar and even intergalactic gas have been detected previously, but not such a region surrounding our own Galaxy.

The Milky Way is a spinning disk of stars, gas, and dust about 100,000 light-years in diameter. The galactic corona found by the two astronomers apparently extends for about 25,000 light-years on either side of the disk. The corona, therefore, is the boundary region between the gaseous interstellar matter found within the galactic disk and the nearly perfect vacuum of intergalactic space. A study of this boundary region may provide new insights about the vast regions of space through which the Milky Way moves.

Since the physical conditions in the corona are influenced by processes occuring on a galactic scale, it is believed the whole galaxy will be better understood by the study of these conditions. For example, from detailed studies of the corona it may be possible to determine if the galaxy has outflowing material in the form of a "galactic wind" similar to the solar wind.

The halo is so tenuous it probably can't be detected with Earth-bound telescopes. To detect the corona, Savage and de Boer said they had to measure the ultraviolet light coming to Earth from bright stars outside the Milky Way. Any gas in between would absorb part of the light, and that would tell the astronomers not only what was there but how fast it was moving.

Earth's atmosphere doesn't pass ultraviolet light, however, so the observations had to be made from space. And because the nearest suitable stars are 180,000 light-years outside the Milky Way, the

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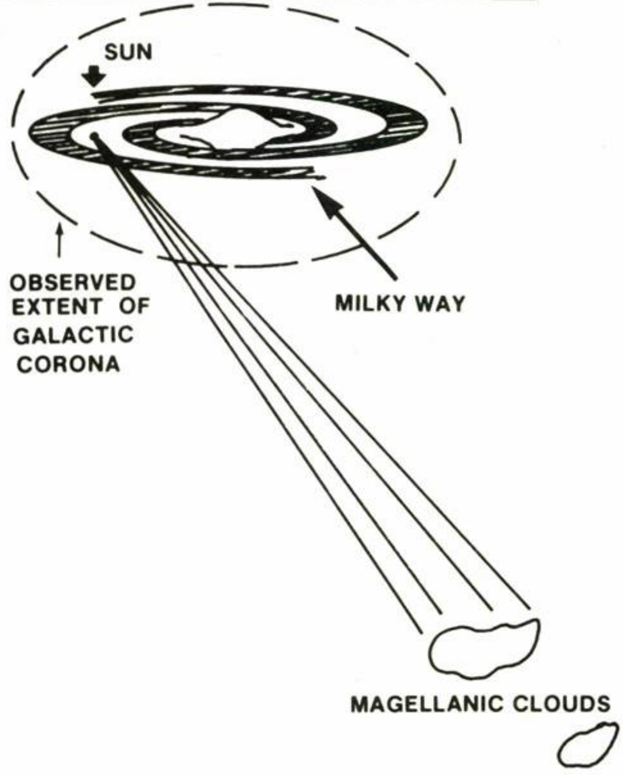


orbiting telescope would have to be very sensitive. Until the International Ultraviolet Explorer was launched late in 1977, Savage said, the experiment was impossible.

IUE tracked and measured the light from individual stars in the Large and Small Magellanic Clouds for up to five hours at a time, Savage said, with a directional accuracy better than one part in 10 million. The spectra showed an intervening gas made up of atoms including carbon, silicon, nitrogen, oxygen, and aluminum, but so hot that some of their electrons had been stripped away.

The corona's origin is not well understood, according to Savage. It could come from the gas and stars of the Milky Way, or from intergalactic space. Savage said the discovery does indicate, however, that coronas — planetary, solar, stellar, and now galactic — may be common phenomena. The discovery also lends support to the idea that radiation from quasars is absorbed by a succession of intervening galactic coronas as the radiation passes through space over billions of light-years before it arrives at the astronomer's telescope. This would mean that quasars, already thought to be exceedingly bright objects, would in fact be even more luminous than previously thought.

Death of the Dinosaurs

Something mysterious happened about 65 million years ago. Geologically, that time is known as a transition period between the Cretaceous and Tertiary periods, and it is marked by the relatively sudden disappearance of half the different kinds of life on Earth. The most famous to vanish were the dinosaurs, giant reptiles that had dominated the Earth for millions of years. The Tertiary period which followed their disappearance saw the rise of the mammals, freed from the threat of predatory dinosaurs, to ascendance and then finally the evolution of man himself.

Scientists have long been at a loss to explain what happened to all those vanished genera. There is no geologic evidence of a climatic change, and theories proposed to account for the disappearance in normal evolutionary terms fail both in explaining its suddenness and the fact that so many different genera, both on land and in water, were destroyed at the same time. One theory, for example, proposed that a certain plant with somewhat laxative properties became extinct, presumably leaving the dinosaurs who had regularly consumed it to die of constipation. But this fails to explain why so many aqueous life forms also vanished at the same time.

A novel explanation for the mystery was first proposed some years ago by the noted Russian astronomer I.S. Shklovskii of the Institute for Cosmic Research, Soviet Academy of Sciences. He pointed out that a nearby supernova, the highly energetic explosion of a star, would bathe the Earth in an immense flood of deadly radiation. If such a supernova had occurred close to the solar system 65 million years ago, the result could well have been the total extinction of half the life-forms on Earth.

The only problem has been a lack of any evidence in support of Shklovskii's hypothesis. Now, however, the first such evidence has been found. Walter Alvarez of the University of California at Berkeley, together with co-workers Luis Alvarez, Frank Asaro, and Helen V. Michel, reported at a recent meeting of the American Geophysical Union that they had detected an extraordinary and sudden increase in the amount of the element iridium in a layer of sedimentary rocks laid down 65 million years ago.

The element iridium is rare on Earth's surface, most of it being concentrated in the core. In fact scientists believe that what iridium *is* found on Earth ultimately has an extraterrestrial origin, settling down in dust from outer space where it is a thousand times more common. Alvarez and his group found that the concentration of iridium in the successive sedimentary layers they were examining suddenly jumped 25 times higher before returning to a normal value 20 to 30 thousand years later. Such a sudden increase, they pointed out, could have been the result of a blast of material from a supernova occurring an estimated tenth of a light-year away.

The researchers found the iridium increase in rocks at a specific site: Gubbio, Italy, where millions of years of systematically laid down sediments have been exposed by road construction. It is possible that only a local effect is involved, such as a river temporarily washing out an iridium deposit, but this can be tested by checking iridium levels in other sedimentary rocks around the world. The case for an extraterrestrial origin would be strengthened if the increase were shown to be worldwide at the same period.

There are also other tests which can be performed. A nearby supernova would have generated a large amount of the radioactive unstable element plutonium 244, which has a half-life of 83 million years. If this isotope were found to be present dating from the transition period 65 million years ago, it would clinch the supernova theory. Preliminary results, however, have been discouraging, and the mystery of the dinosaurs' demise is still far from solved.

More Black Holes?

Black holes, those mysterious objects predicted by the equations of modern relativistic astrophysics, both intrigue and fascinate scientist and layman alike. Yet to date no real example of a black hole has been identified beyond doubt, although a number of probable candidates have been found.

Most recently, two more such candidates have been proposed, based on unique observations and clever reasoning. The first is Cassiopeia A (Cas A), long a mystery to astronomers. Cas A, one of the first radio sources detected when radio astronomy was still in its infancy, turned out to be the strongest radio source in the sky at long wavelengths. A rapidly expanding ring of gaseous filaments visible at optical wavelengths is identical with the radio source, and demonstrates that Cas A is some form of supernova remnant.

The problem is that the measured rate of expansion *indicates* that the supernova event took place relatively recently — sometime in the 1660s, in fact. A supernova at the distance of Cas A (9000 light-years) should have been visible on Earth as a star brighter than zero magnitude at least. Yet no such "new star" was observed anywhere in the world, despite the considerable amount of astronomical activity during that time.

Now the Russian astrophysicist Iosef Shklovskii, writing in *Nature*, has proposed that the star which gave rise to Cas A was a very massive star, twenty times the mass of the Sun, which collapsed to form a black hole instead of a neutron star (the normal end-product of a supernova explosion). He argues that the absence of a central neutron star would have prevented the supernova from becoming bright enough to be observed.

Theory indeed predicts that a star of twenty solar masses should collapse into a black hole rather than a neutron star or pulsar at the end of its life, and observations with the orbiting Einstein X-ray Observatory show no neutron star is present. A black hole, on the other hand, is not expected to emit X-rays — or anything else.

Shklovskii also points out that the strongest evidence is the lack of heavy iron-group elements in the observed remnant. Such elements, present in the core of a dying star, would have been at least partially dispersed by the force of the supernova explosion — unless the core had collapsed totally into a black hole.

The second candidate is not so much a new candidate as a suspect for which new evidence has been found. It is the giant, highly active galaxy M-87, a member of the huge Virgo cluster of galaxies. Long known as an active radio source,.M-87 has now been found to emit extremely short and rapid pulses of radio waves less than a thousandth of a second in duration.

Reporting their discovery to a meeting of the American Astronomical Society, Joseph Erkes and Ivan Linscott of the Dudley Observatory in Albany, New York, pointed out that the peculiar form of the radio bursts indicates that they are due to material falling into a superdense object, such as a black hole. Their observations were made with the Arecibo Observatory's 1000 foot radio telescope in Puerto Rico, the largest single dish in the world.

Astrophysicists have suspected for some time that the enormous release of energy associated with both active radio galaxies and quasars may be due to material spiraling into a huge supermassive black hole. Some have even proposed that such giant black holes are the "nuclei" around which galaxies form. Again though, many more observations are necessary to establish the precise nature of the source. Still, each such piece of evidence increases the probability that black holes not only exist, but play a very important role in the life of the universe.

The Lunar Treaty

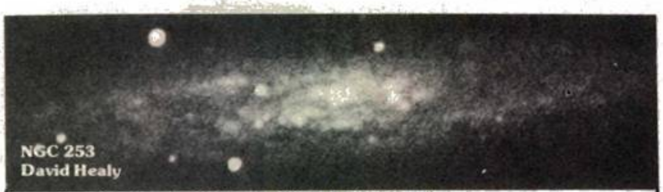
It may be years before men walk on the Moon again but when they do, they will be walking on a "common heritage of mankind."

Those are the words used in a new outer space treaty recently approved by the United Nations' 47-member Committee on Outer Space. They mean that no part of the Moon nor any of its resources can become the property of any country, although individual countries are free to conduct any explorations. Even though commercial exploitation of lunar resources is many years in the future, such a statement means that smaller countries lacking a spaceflight capability will share in the Moon's mineral wealth.

The new treaty also repeats earlier prohibitions against military use of the Moon or lunar space. In particular, nuclear weapons and other weapons of mass destruction can neither be launched nor placed in lunar orbit.

The proposed treaty also requires both the Soviet Union and the United States to speedily report their scientific findings to other countries.

The treaty, seven years in the making, must still be approved by the United Nations General Assembly, which meets in September, before it is submitted to individual governments for ratification. The treaty will come into force when five countries have ratified it.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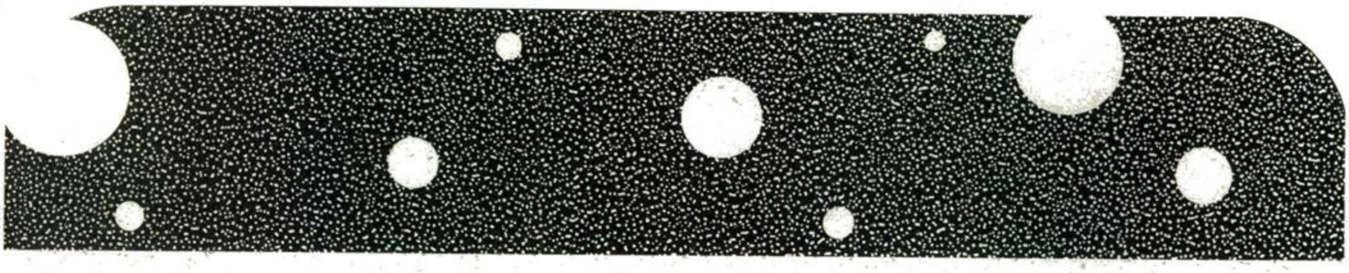


STELLAR FRONTIERS

Stellar Formation

by
Martin Cohen

Our destiny may well lie in the stars; our chemical origin certainly does. As long as Man has been aware of his surroundings, he has puzzled about the nature and source of the stars. But now there is a quickening of the pulse — and pace of research — among astronomers: by a combination of new technologies in different parts of the electromagnetic spectrum, it has become possible to apply subtle new techniques to the observation of star formation.

The symbiosis between theory and observation in astronomy is rarely a simultaneous process. Commonly the existence of a piece of data triggers some kind of attempt at theoretical explanation. Observations are made to test the specific predictions of models or to differentiate between different conceptual approaches to a problem.

At present, theoreticians are recalculating the earliest phases of collapse that convert a large, diffuse, dusty gas cloud into a young star. Their initial computations, carried out in the sixties and early seventies, seemed credible enough to cause a Berkeley colleague, Leonard Kuhi, and myself to embark upon an enormous program of observations. We started almost five years ago, and had a number of quite specific issues to investigate, as well as the general objective of deciding between two quite different sets of calculations. Let's consider the conclusions of our study in the form of some answers to the most commonly-asked questions in the field of star formation.

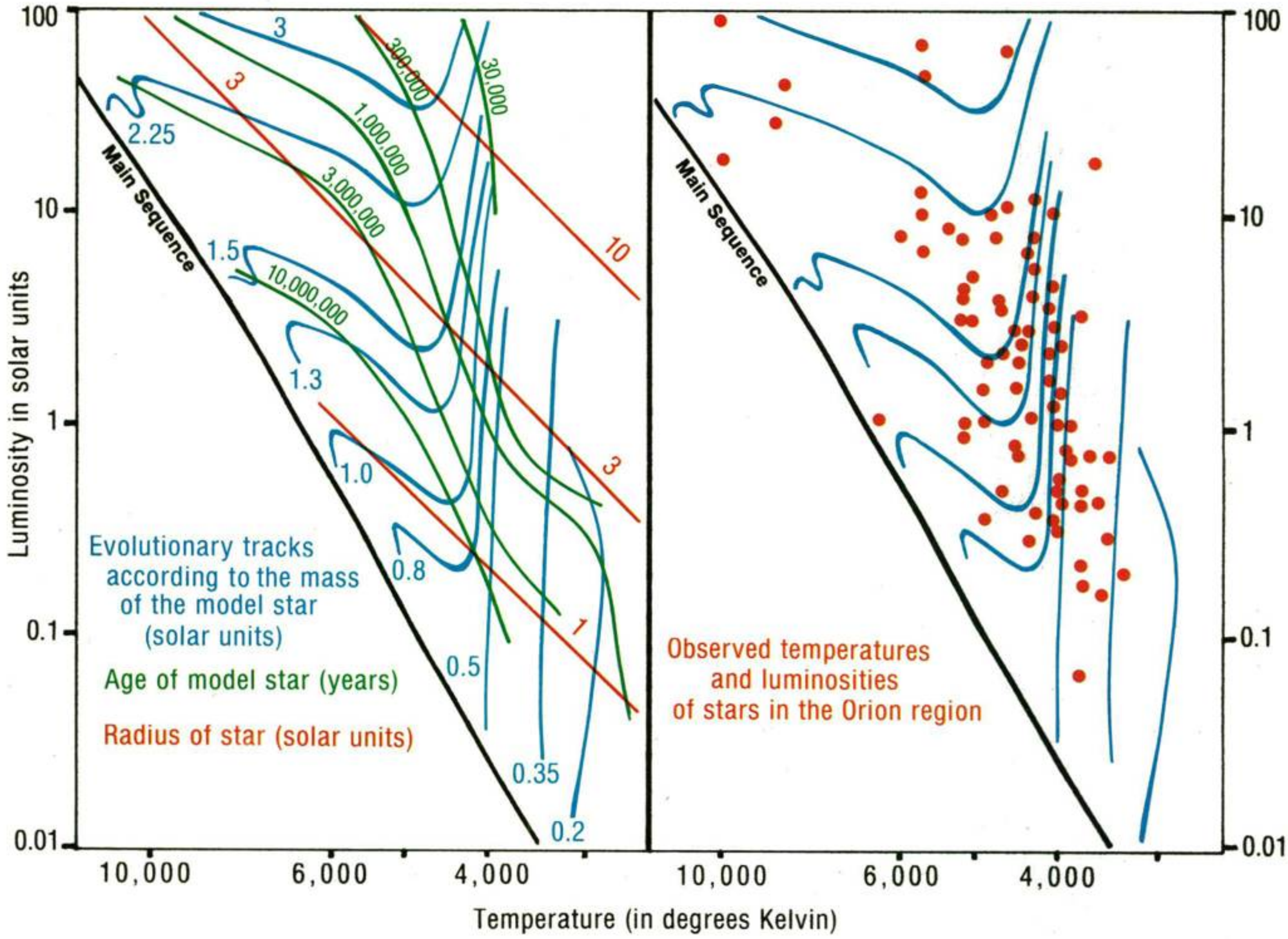
The first thing to keep firmly in mind is the meaning of the word "young." Often astronomers use the word "young" in place of the word "unevolved." The distinction lies in the wide range of rates at which stars of different mass collapse from parent clouds into stellar cores and later consume their inner nuclear resources. A star ten times the mass of our Sun evolves on a much more rapid time scale than the Sun. For such a star, the early phases of shrinkage from a cloud to a dense protostellar core occur several thousand times faster than our Sun's initial contraction. In fact, in the time that our Sun took for its initial contraction, a star ten times as massive would have contracted from a gas cloud, reached maturity as a nuclear-powered entity, and evolved into the latter phases of its life. Such a star would be not only young, both in years and by solar standards, but evolved. Henceforth, when astronomers use the word "young," you should understand it to mean "unevolved" and should be aware of this strong dependence upon mass.

The high-speed evolution of massive stars is useful to astronomers, for these stars don't have an opportunity to wander far in space from their birthplaces. The hottest, bright blue stars are thus good signposts to regions of recent star formation. If we examine all the stars that lie in such a region we should find the vast majority of them have low mass, and a very large number exhibit a particular array of emission lines in their optical spectra. The strongest of these lines is a red line of hydrogen and its presence in emission is a first indicator of youth in low mass stars.

Dr. Kuhi and I began our study in 1974 armed with a catalog containing about 300 of these hydrogen-emission stars that were believed to represent young objects. How were we to turn our observational data into material directly comparable with theory? One prime meeting place for observation and theory in the field of stellar evolution is the historic Hertzsprung-Russell (H-R) diagram. As originally devised, the H-R diagram was simply a plot of absolute visual brightness against spectral type for a large number of stars. The points representing these stars turned out not to be randomly sprinkled through the diagram, but rather defining an apparently continuous swath from a few luminous blue objects to a mass of faint red ones. This swath we term the *main sequence*. It represents the locus of mature stars seen in our neighborhood of the galaxy. To an observer a star is characterized by two parameters, today refined a little in comparison with the early H-R diagrams: these are the temperature of the outer atmospheric layers (which is related to color — blue stars are hot, red are cool) and the luminosity (now taken to be the total energy output at all frequencies, not just in the tiny visible portion of the spectrum).

It is the collapse of a distended dusty cloud under gravity that ultimately leads to the formation of a young star. For a theoretical astronomer, modeling this process is a legitimate goal, but not an easy one. A realistic calculation of the evolution of such a collapsing cloud should include as input parameters: the initial rotation of the cloud; any magnetic fields that might thread through the regions of the cloud prior to contraction; the chemical evolution of the gas and dust (i.e., which molecules are built up or destroyed during the collapse); and a consistent and complete physical description of the collapse, including the effects of shock waves, produced during the shrinking of the cloud into a central core, on

The Great Nebula in Orion is a chaotic region of star formation full of twisting, glowing gas and dark, obscuring dust. The brilliant blue stars of the Trapezium are the obvious "young" stars (young in the ordinary sense of "not old"), but buried in the gassy folds of the nebula are the truly "young" stars, stars that have not yet evolved. Painting copyright © 1979 by Geoffrey Chandler.



The theoretical H-R diagram (left) may be compared to the observational diagram (right) to learn the physical characteristics of newly-formed stars. The blue tracks show the path a cloud of given mass will follow as it evolves toward being a star; green lines give the number of years from the beginning of collapse; and red lines show the radius of the star. In the observational plot for objects in the Orion Nebula, the star's positions were determined from optical and infrared data. Diagram by Martin Cohen.

the still-infalling matter. Such a complex calculation cannot yet be performed, and the history of protostellar evolution modeling is one in which only those parameters considered to be most crucial (and most manageable) have been incorporated. To a theoretician who wishes to make predictions about the appearance of a young star, there is also a pair of crucial quantities: the mass of the original cloud (or, equivalently, the ultimate mass of the star to be formed) and the length of time elapsed since his model was permitted to begin shrinking.

The earliest generally acceptable models conceived of two phases of stellar evolution towards the main sequence. Since the energy of the protostar is drawn largely from the gravitational potential energy of the parent cloud, in the first phase, the *convective phase*, this energy leaks from the stellar core (thereby enabling further collapse) by means of convection currents that stir up the forming star, mixing deep interior and surface. Later the internal transport of energy is achieved by means of radiation and the star enters the *radiative phase*. The convective phase persists for only about a million years (for a star like our Sun) while the radiative phase lasts for tens of millions of years, and the final approach to stellar maturity is enormously more protracted.

In the early 1970s, a new approach to stellar evolution was formulated by following the dynamical collapse of the parent cloud. This theory predicted stellar behavior more complex than the convective-radiative picture. Our first observations, however, were sufficient to rule out the dynamical models. We adopted, therefore, a convective-radiative framework within which to interpret our studies. (In the coming year, more accurately formulated dynamical models will be forthcoming and, of course, we will re-evaluate them.)

The collapsing protostar's model parameters can be plotted on an H-R diagram. The curves that result represent the evolution of the young objects. In the convective-radiative models, every star that we are likely to encounter lies on one such curve. Consequently, if we measure temperature and luminosity to locate a star in the H-R plane, the model will predict a unique combination of mass and age for that star.

We proposed to employ the H-R diagram in just such a manner. For our data on stellar temperatures we used the big 120" reflector of the Lick Observatory above San Jose, California. A powerful modern spectrograph linked to an electronic reading system which scans the spectrum and stores the data in a computer had been made available on this instrument (see "The Revolution in Astronomy," ASTRONOMY, November 1977, p. 6). In fact, it was the powerful spectrograph's capabilities that provoked our giant study. It made possible the investigation of far fainter stars than previously had been studied. Recognition of absorption features in the spectra enables a determination of temperature, as the cool outer gases of a star absorb the radiation passing from the hotter inner layers. This powerful instrument also readily reveals the bright emission lines that are diagnostic clues to the youth of a star.

What we then needed, as a parallel study, was a good measurement of the total luminosity of stars — not merely their visible output. Research work in the mid-1960s had revealed that young stars produced far more radiation at long infrared wavelengths (beyond 20,000 Angstroms, or 2 microns) than was expected. Consequently, in order not to miss any energy, we needed extensive observations at these wavelengths of every star we had examined optically. To acquire all the necessary observations on over 500 stars took us more than three years. Had they been ordinary stars, it would have been extremely difficult (and at some wavelengths impossible) to measure the infrared energy because of the limitations in sensitivity imposed by the technology required for work in this region of the spectrum. However, precisely because these are young stars, they possess an excess of radiation in the infrared and this enabled us to obtain much more accurate estimates of stellar luminosity than previously were available.

I even observed some stars at still longer wavelengths, out in the radio spectrum, to be absolutely sure that we weren't missing other significant radiation. This multi-disciplinary approach, to my mind, makes modern astronomy an especially fascinating field. We had "only" to assemble all our optical and infrared observations, plot our H-R diagrams, and answer the burning questions about star formation. It took fifteen months to complete that phase of the investigation.

But I won't try your patience; here are the answers.

In general, we're going to explore the ranges of typical young star parameters such as radius, surface temperature, and total luminosity. You can see one of our H-R plots for yourself (opposite page). This diagram shows all the young stars in the region around the misty tip of Orion's Sword, the Great Orion Nebula (M-42) that have optical hydrogen emission lines. This diagram of a stellar nursery contains a tremendous wealth of information. By comparing it with the adjacent interpretive diagram, we can derive a quick estimate of a star's radius, mass, and age. Typically, young stars have a temperature of 4000 degrees Kelvin, radii of one to a few times that of our Sun, and masses a little less than solar. Their ages usually range from a few hundred thousand up to a million years.

If we examine the region of our galaxy close to the Sun we find that stars occur with a wide range of masses, the vast majority less than that of the Sun. The particular proportions of high and low mass stars in the solar neighborhood must represent an average of all the different processes by which, and locations in which, star formation has taken place. In our region of space stars from many sources are thoroughly mixed.

But we know that young stars are gregarious creatures and are found in abundance in regions of space rich in thick, dark, obscuring material. Such dark clouds, filled with gas and dust, represent the birthplaces of stars.

Now, let's become specific in our questions. First, how many high and low mass stars have these giant nurseries manufactured, and is the proportion between these masses constant from nursery to nursery? Or phrasing the question somewhat differently, do some clouds specialize in low mass stars while others specialize in more massive suns?

From the H-R diagram we can determine the distribution of stars by mass in the Orion nursery. Of course, we should remember that such a distribution is likely to be most reliable when obtained for the closest nurseries to the Sun. (As our attention is focused on more and more distant dark clouds, the faintest stars are lost to our view, producing a selection effect.) Our conclusion, based on the most reliable determinations to date, is that young stars are "born" with the same ratio of high mass to low mass stars as that found among the stars in the Sun's vicinity. This is not an unexpected result, but nevertheless a gratifying one that lent us confidence in the efficacy of our analytical methods.

A cluster of hot young stars shines near the core of the Lagoon Nebula. What appear to be gaps in the nebula are actually dark clouds seen silhouetted against gas glowing in the intense light of the cluster stars.

Secondly, do we find stars of all masses present in the same nurseries, especially the heaviest stars (up to fifty times the solar mass) and the lightest that theory predicts can be self-luminous and hydrogen-burning (about one tenth of a solar mass)? Orion, for example, is rich in bright blue stars with the very highest masses, whereas in the dark clouds in the direction of Taurus we don't see such heavy stars. It appears that with the exception of the very heaviest stars, each stellar nursery produces stars in all sizes.

Third, do heavy and light stars form in the same regions of dark clouds? Evidence exists in the Taurus region that, when high mass stars (here we mean stars greater than about four solar masses) have formed, they have done so preferentially in the very dense gaseous centers of the clouds. The lower-mass objects are seen in the surface layers. Of course, it's quite likely that these lower-mass stars occur throughout the dust-laden parent clouds and that it's only a matter of how much dust our line of sight can tolerate before we cease to penetrate any further into nurseries.

Fourth, given that star formation is occurring in some complex of dark clouds, with what efficiency does it take place? In other words, what percentage of the total mass of gas (with hydrogen the most abundant ingredient) in these clouds will ultimately find its way into stars? (The answer to this question should give a hint as to the longevity of stellar nurseries. If the efficiency is very high, then the birth of each generation of stars will appreciably deplete the total reserves of dark cloud material, thereby shortening the epoch over which the clouds could produce stars.) How can we estimate the efficiency of star formation? The simplest method is to assess for an entire nursery the total mass observed in young stars and to divide this by the total gas mass within the clouds. But that's easier said than done.

Today, probably the best estimates for the total mass of gas in a dark cloud are derived from radio observations of specific molecules such as carbon monoxide. Optically we see only a little way into a thick cloud. Clearly we cannot assess a total mass at visible wavelengths. The infrared wavelengths most accessible to ground-based work are sensitive to deeply embedded stars but not to the large quantities of gas between the stars. However, in the radio, we can detect molecules throughout a gas cloud. All that we need in addition is the ratio of the number of hydrogen molecules (the principal molecular component of clouds) to the number of the particular molecules we are observing, and we can calculate the total mass of gas.

The radio molecular picture of the Taurus dark clouds for example, is quite different from the optical. On photographs the clouds appear to be messy, randomly distributed blotches. In the radio there is a beads-on-a-string structure, in which dense blobs are bathed in an elongated, more tenuous background of gas. By using radio we can focus our attention on these individual blobs and make a much more sensitive count of the population of young stars within these small volumes. The totals derived in this manner suggest that the efficiency of star formation is around a few (up to ten) percent. Such numbers suggest that the clouds have lifetimes on the order of a few tens of millions of years.

Finally, does star formation occur spontaneously in a nursery, or only in response to some trigger, perhaps external? The issue of possible external trigger mechanisms starting the collapse of clouds is still a knotty one and there are no satisfactory observational answers as yet. Some theoreticians have argued that the blast waves traveling through space from supernovae might act as triggers to star formation when they impinge upon dark clouds. Certain isotope abundance anomalies in the solar system suggest that the Sun's formation was, perhaps, supernova induced. We hope to test trigger theories very critically in the coming year — but it's premature to speculate.

Let's turn now to a more penetrating question, one increasingly pertinent as we obtain many views — each somewhat different — of the interiors of clouds via their various radio molecular emissions. What happens to the remaining cloud material *after* stars have formed? Is there some feedback? Are there interactions between young stars and their environment that might significantly affect the subsequent evolution of the clouds?

One way we might theorize about this is the following: consider a cloud core in which a simple massive hot O-star has formed. Throughout the cloud, surface and core alike, lots of low mass solar-type stars are forming. One effect the O-star has on the ambient gas and dust is radiation pressure; the flux of stellar radiation itself acts to push away dust grains which jostle gas atoms and molecules. In short, a highly luminous star would soon stir up the cloud core, eventually dispersing the central material totally. The consequence would be that potential sites of low mass star formation would be swept away, perhaps even hindering already-collapsing stars. We feel that it's likely even low mass stars have very sizable stellar winds (maybe a million times as active as the Sun's) during the earliest phases of their evolution. Conceivably then, a high enough frequency of active small stars could exert a similar dispersal effect on a cloud as does one very luminous object.

Another question: Do all the stars being formed in a complex begin to collapse from their parent clouds at the same time (a process referred to as *coevality*)? Do we see evidence for such a phenomenon? Suppose we ask "What is the distribution of ages of stars in a single nursery?"

We find that, rather than there having been an obvious triggering, stars have apparently been forming continuously throughout the history of a dark cloud. In fact, if we look at our data from a different perspective, we find a seeming acceleration of star formation in all the major nurseries. In other words, the more young stars we see in a cloud, the more that cloud seems to be producing now. Of course, we can see another interpretation of this: the more stars that have formed, the greater is their sweeping action on the cloud, and the more we are able to see already-formed stars previously hidden behind obscuration. So stars like the Sun, or even stars less massive, may be very efficient "brooms" in their first fifty thousand years of life.

How many young stars form as single entities and how many form as binary systems? (This question arises because it is known that in maturity many stars in the solar neighborhood are members of physically bound pairs of stars. See "Stars with Companions," ASTRONOMY, September 1977.) If the hydrogen emission line stars, which are frequently observed, actually are the precursors of main sequence stars (frequently found to be in binaries), what evidence exists for their binary nature when still young?

At the moment we can say only the following on the basis of our data: apparent pairs of young stars (i.e., those separated in the sky by only a few arc seconds) are, in all probability, binaries if both show emission lines. However, these are rather widely separated systems. Spectroscopically we see no indications for dual stellar characteristics. Therefore, either putative companions have much lower luminosity than the primaries (and hence much lower mass), or the spectral types of both stars are sufficiently alike that their composite radiation presents a single homogeneous spectrum. The issue is crucial but at present the most fruitful path of inquiry is to obtain repeated photographic spectra of the brighter young stars at sufficient spectral resolution to monitor the velocities of the principal absorption lines. Regular periodic variations in these velocities would point to the existence of companion stars.

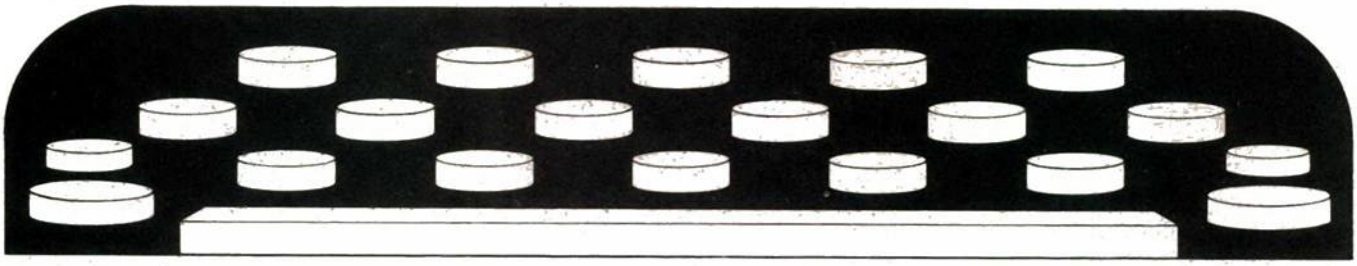
Finally, what do astronomers generally look for to establish an object as unequivocally "young"? A prime candidate for a youthful — that is, unevolved — star is a coolish, low-mass star, with an active stellar wind surrounded by a cloud containing dust grains. For the observational astronomer, this means a late-type spectrum (G, K, or M) with emission lines superimposed, and an infrared excess. The stellar wind is responsible for the emission lines, the dust cloud for the infrared.

The dust grains have temperatures in the range from about 1500° Kelvin to at least as cool as 500° (deduced from the infrared data). The heated grains physically belong to the star and populate a so-called circumstellar shell of gas and small particles originally part of the parental clouds.

Now that we have at least a sketch of the properties of young stars, it is tempting to endeavor to conceive the properties of even younger ones. The youngest low-mass objects that we have studied are a mere 30,000 to 50,000 years old, truly an unevolved state!

We hope that the results of our work will stimulate further research as theoreticians scramble to produce new models for comparison with the observations, and observers are prompted to ask better-informed and perhaps more quantitative questions.

Dr. Martin Cohen is a British astrophysicist now working at the University of California, Berkeley.



Sir / Reading H. Halvorsen's "I'm Not Worried "(Forum, July 1979) is a little like reading some nineteenth century prof's assertation that powered flight is mathematically impossible. This guy is hilarious; he takes figures out of books and conclusively proves that we can't go out tomorrow and convert to SPS. I could just as easily prove telephones are impossible with Edison's technology. Hats off to Mr. Halvorsen. He proves conclusively that the world will never lack for smug idiots with a hatful of figures and a load of snide comments.

Martin Halbert
Houston, TX

Sir / In response to the article by Mr. Halvorsen:

I'm not worried either — either for the Solar Powered Satellite or for the future of astronomy. If the SPS is not implemented, it will not be for any of the reasons given by Mr. Halvorsen. His facts are misleading and myopic. Let me dispute them.

Solar cells cost too much. If they really did, engineers would have shelved the concept long ago. Mr. Halvorsen assumes that technology and the marketplace are standing still. Volume production, new technology, extraterrestrial resources, and manufacturing plants in space can cause the price of solar cells to drop dramatically. Nor are solar cells the only option in SPS design.

Launching the materials for an SPS into space is a formidable task. Is it impossible because it looks like the old Saturn V is too little for the job? Mr. Halvorsen should talk to Boeing or Rockwell and see if *they* think the job is too big. They and others are designing heavy lift launch vehicles that will make the cost of lifting objects (and people) into space cheaper and cheaper. The SPS would give a tremendous boost to the development of launch vehicles. It is likely that only the first SPS would be built from Earth materials. Materials from the Moon and near asteroids are far cheaper for the long-term manufacture of SPSs.

Harmonic interference. Yes, even one ten-gigawatt SPS will almost wipe out Earth-based radio astronomy. 180 microwave SPSs in geosynchronous orbit would also obliterate optical astronomy. Contemporary forms of electronic communications could possibly be disabled by a few SPSs, even though they use a one-kilometer diameter antenna to form a very tight beam. These things may all be true, but they don't bother me. There are alternative channels of communications being made possible with lasers and fiber optics. There are also alternatives to Earth-based astronomy. The alternatives are better than what we now have.

International law would seriously restrict the beaming of microwave energy. When has an international law ever stopped a sovereign nation from doing what it believes it must? The world is running out of cheap, clean fuel. Laws will change when necessity makes them change.

The SPS is vulnerable to attack. Mr. Halvorsen should acquaint himself with some of the growing body of literature on space warfare. The SPS need not be vulnerable. The SPS can be defended more easily than it can be attacked. Time, distance, and visibility in space all work in favor of defense. Keep in mind that an SPS produces a staggering amount of power — power that can be diverted to a laser or particle-beam weapon. Such a weapon would not be dangerous to a target on the distant Earth, but should handle an incoming missile.

Certain scarce materials may make the SPS too expensive to build. I can make a longer list of critical materials than Mr. Halvorsen can. For the short term, some of these materials may cause a problem. We may have to pay for them through the nose, but it will still be worth it. In the long run, I believe space holds all the materials we will need.

If the SPS is determined to be the best solution to the base-line energy problem (hopefully in tandem with local solar power and energy-efficient building designs), it will bring about a major change in our style of life. Energy will become relatively cheap on Earth. The night sky will be flooded with light from the huge satellites. People will begin to live for indefinite periods in space and a new civilization in space will begin.

I personally look forward to the view to be had from the orbit of the Moon, and I don't plan on looking back. The SPS may be the key to unlocking the gateway to space.

Warren Merkey
Gainesville, FL

Sir / People who are concerned about the impact of power satellites on astronomy would do well to take them seriously instead of laughing at obviously unworkable designs such as Halverson's. The potential harm to optical and radio astronomy is at least as serious as that posed by the growing effects of city lighting and radio and microwave transmissions.

However, solar power satellites also offer unprecedented opportunities for astronomers. The advances in space transportation and large space structures that could be financed by the SPS project will enable relatively cheap construction of space observatories with the capacity to observe all frequencies of the electromagnetic spectrum (no atmosphere to block or garble reception). In free fall optical devices can be huge because there is no gravity to distort their shape. Interferometers can be built with baselines in excess of 10,000 km. The only limiting factor will be the timekeeping and computing power to synthesize the image.

Imagine mapping the continents of planets 60 light-years away. Witnessing, in high resolution, the birth of the Universe. And more, more....

As long as space is remote and expensive, astronomers will be restricted to a few small orbiting systems. But when thousands of construction workers live and work routinely in space, as would occur with the SPS project, even an amateur astronomer who can afford the cost of a round trip vacation to Australia — what a trip to space could cost in the year 2000 — can have access to equipment that only a handful of professional astronomers can even dream of using today.

If this idea appeals to you, give solar power satellites a chance. By all means demand that the Dept. of Energy include funds to replace Earth-based observatories hampered by SPS effects with space telescopes. It looks as if this would only raise SPS costs a few percent. But don't throw away the biggest opportunity astronomy ever has stumbled across just to protect a few telescopes stuck under a hazy, wavering blanket of air.

Carolyn Meinel Henson
L-5 Society
Tuscon, AZ

A detailed description of SPS design is available in **Satellite Power System Concept Development and Evaluation Program**, *October 1978, available from the National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, VA 22161 for $11.75.*

Sir / The article entitled "The Moon: the Southern Highlands" in the June 1979 issue of ASTRONOMY mentioned that "Rand McNally has a series of wall-sized lunar charts...." Your readers may be interested to know that the Hansen Planetarium bought Rand McNally's entire supply of these charts in 1977. I have spoken with Rand McNally's map department and they confirm that lunar maps are no longer available through them. Persons wishing to purchase the Rand McNally Moon Maps should contact the Hansen Planetarium at 15 South State St., Salt Lake City, UT 84111.

Patrick A. Wiggins
Salt Lake City, UT

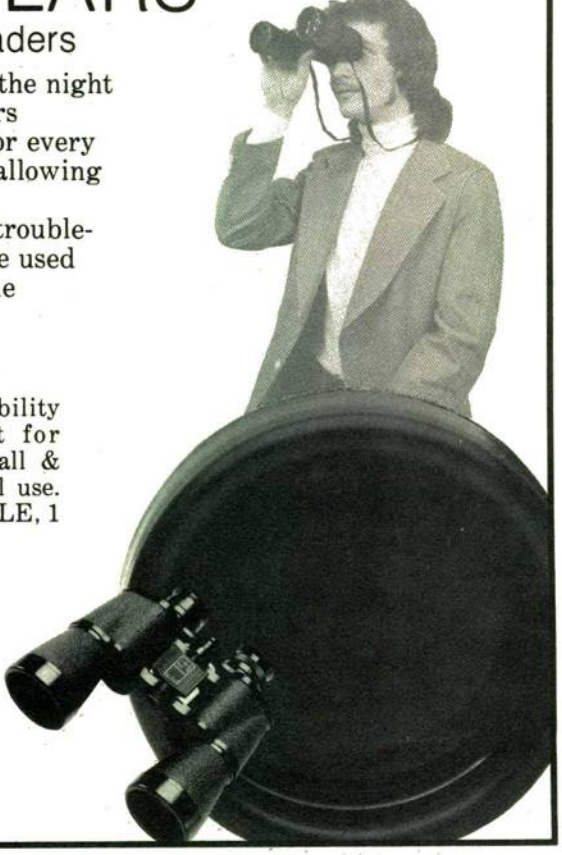
Sir / The following experience might be of interest to your readers. Last January 24, I observed the Moon and Venus at around 6:00 a.m. The angular separation between them appeared to be roughly 3°. The Moon was nearing its new phase (I estimated it to be around 30° west of the Sun). Using the Moon as a guide, I was able to observe Venus in broad daylight at 9:30 a.m. I checked the observation at five minute intervals to be certain. Merida, Venezuela, where I made the observation, is located approximately 9° N latitude and 71° W longitude.

Lawrence W. Vincent
Merida, Venezuela

Sir / You've stated in two articles ("Voyage to the Stars", March 1975, and "Beyond Centauri", April 1978) that in a spaceship traveling at a speed close to that of light, the stars in front and in back of the ship will change color and disappear. Well, this is not the case. Since a star gives off light in almost all parts of the spectrum, as you move forward at greater and greater speeds, the light that you see will be shifted to a different part of the spectrum. So, when looking back, you will be seeing the light coming from the radio end of the spectrum, and if you look forward, you will view the gamma ray end of the spectrum. Thus, the only way a star can change color is when the amount of light given off by one part of the spectrum is significantly different than the other parts.

Richard Blair
Fairborn, Ohio

Mr. Blair / Your last point happens to be the case. Stars do not radiate an equal amount of energy at all wavelengths. A maximum occurs in a particular part of the spectrum, giving each star a distinctive color which actually depends on its surface temperature. The Sun's maximum occurs in the yellow part of the spectrum, and so from a spaceship traveling at high speed away from the Sun, its color would appear more red. The exact shift, of course, depends on the spaceship's speed of recession. For more on star colors and their origin, see February's Star Dome.



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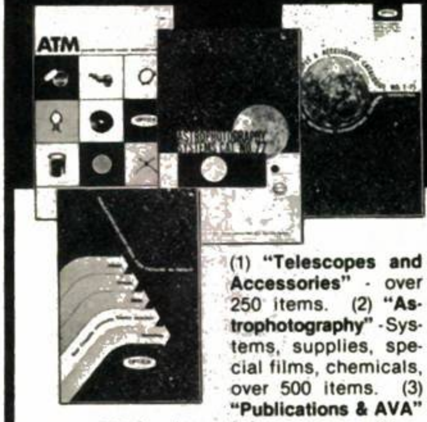

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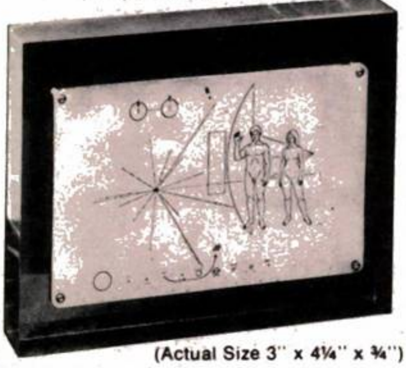

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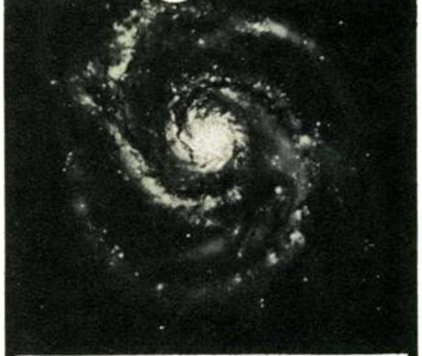

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ANNOUNCEMENT — Buffalo Astronomical Association meets on the 2nd Friday of each month at 8 p.m. (except July and August). Place: Museum of Science Humboldt Pkwy. or Science Aud. of Buffalo State College, 1300 Elmwood Ave., Buffalo, NY. For information call Carl T. Milazzo, (716) 688-7620.

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ANNOUNCEMENT — ABC is cancelling Battlestar Galactica. Please write to ABC urging against this action. Send to ABC-TV, 4151 Prospect Ave., Los Angeles, CA 90068.

ANNOUNCEMENT — SCI-CON 1, a Science Fiction/Star Trek Convention, will be held Oct. 12-14, 1979 in Hampton, Virginia. Guests of honor: David Gerrold with Frank Kelley Freas and Dr. Jean Lorrah. For information send SASE to Charlotte Yielding, P.O. Box 6259, Newport News, VA 23666.

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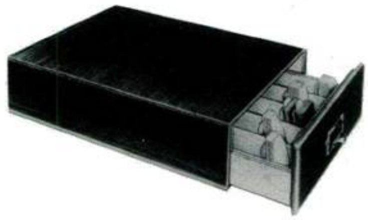

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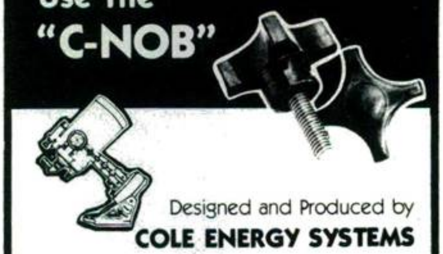

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ANNOUNCEMENT — Future Party '79. Science-fiction/science-fact convention, November 22-25, 1979, Albany, N.Y. Asimov, Sturgeon, von Puttkamer, films, activities. Come celebrate the future. For informational flier, send SASE to Future Party, 606 Horizon View Dr., East Greenbush, NY 12061.

ANNOUNCEMENT — You're help is needed. We must stop the downgrading of the U.S. Space Program. Funding cuts to NASA must be reversed. Write with suggestions to Pat Giddings, R.R. #2, Box 8, Cicero, IN 46034.

ANNOUNCEMENT — Philadelphia based Delaware Valley Amateur Astronomers meet the 2nd Friday of every month at the Schuykill Valley Nature Center in Roxborough. Activities include regular star parties and astrophotography. Contact Ed Kaczanowicz, 434 E. Rockland St., Philadelphia, PA 19120. Phone (215) 457-8470.

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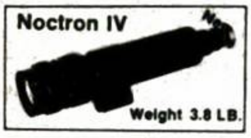

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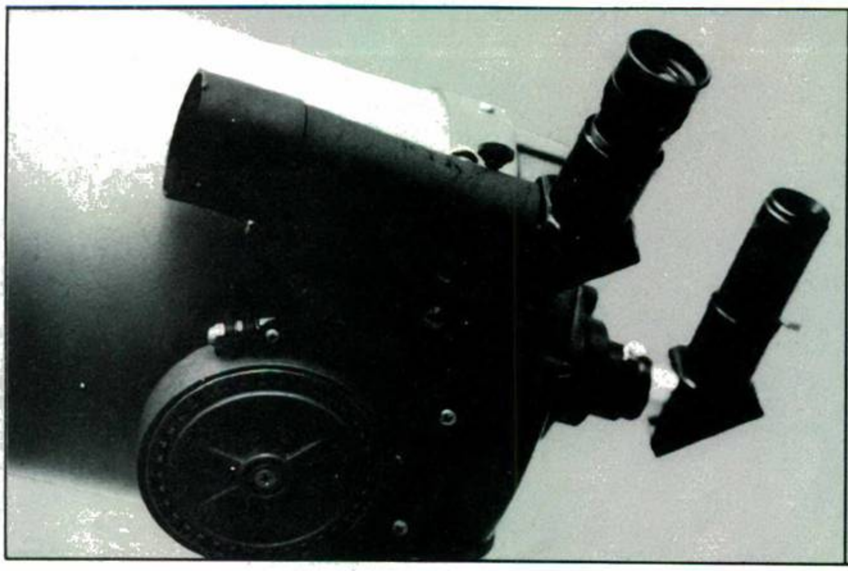

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STAR DOME

SEPTEMBER

by
Dewey Schwartzenburg
and
James Mullaney

Autumn weather often brings those crisp, crystal clear nights so prized by astronomers. It is on such nights when there is no Moon as well that anyone who looks up at the sky (from a site suitably remote from our glowing cities) is immediately struck by the incredible multitude of stars so easily visible. At such times the most mundane of persons feels the attraction of astronomy: "George, come look. There are millions of stars out tonight!"

Of course we can never see millions of stars with our naked eye, but just how many *are* visible? Some people, of course, can see fainter magnitudes than others, but as a general rule the limit for the average person's eye is about sixth magnitude. How many stars are there in the sky brighter than this?

For the first few magnitudes counting is easy. There are 22 stars brighter than magnitude 1.50 (including Adhara [Epsilon (ε) Canis Majoris], a somewhat doubtful case), and 69 more stars of the second magnitude (from 1.50 to 2.49). The class of third magnitude stars includes 187 more, and the fourth magnitude brings in about 550 additional members. This brings us to a total of over 800 stars brighter than magnitude 4.5, which could be seen easily even on nights that aren't particularly clear. (Of course that's 800+ in the whole sky, half of which is visible at any one time, so only about 400 could actually be seen.)

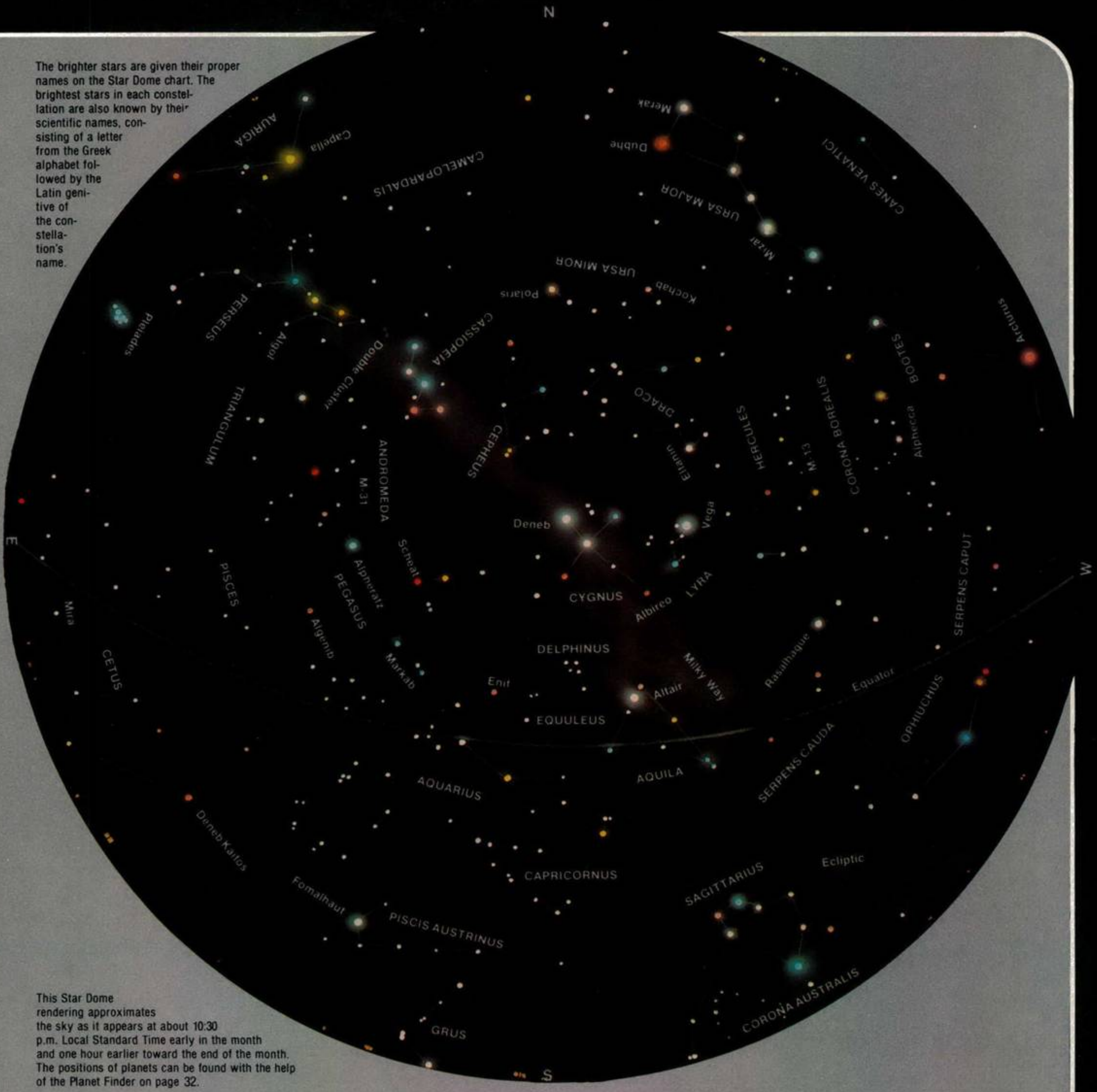
In the fifth magnitude we estimate there are about 1600 more stars, and the sixth magnitude class will add a final 4800 to the total. This means that those with excellent sight — who can see down to magnitude 6.5 — are theoretically capable of seeing well over 7000 stars. Most people, however, would be able to see less than 6000 stars even under the best of conditions.

But wait! That's 6000 stars in the whole sky, both northern and southern hemispheres. Unless we live right on the equator, there is a whole region of the celestial sphere which we never see — around the south celestial pole for those who live north of the equator and around the north pole for those south of the equator. The size of this "invisible" region is determined by how far north or south of the equator we are, ranging from zero on the equator itself to fully half the sky at the north and south poles.

Let's consider the poles first. How many stars could the average person see from the north and south poles? Interestingly enough, it turns out that the answer is different for the two poles.

The southern hemisphere does better in terms of first magnitude stars, having 13 in comparison to the north's 9. The south also beats out the north in the second magnitude class, 38 to 31, and again in the third magnitude class by about the same

The brighter stars are given their proper names on the Star Dome chart. The brightest stars in each constellation are also known by their scientific names, consisting of a letter from the Greek alphabet followed by the Latin genitive of the constellation's name.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AQUARIUS
Deneb Kaitos
CAPRICORNUS
Ecliptic
SAGITTARIUS
Fomalhaut
PISCIS AUSTRINUS
CORONA AUSTRALIS
GRUS

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month and one hour earlier toward the end of the month. The positions of planets can be found with the help of the Planet Finder on page 32.

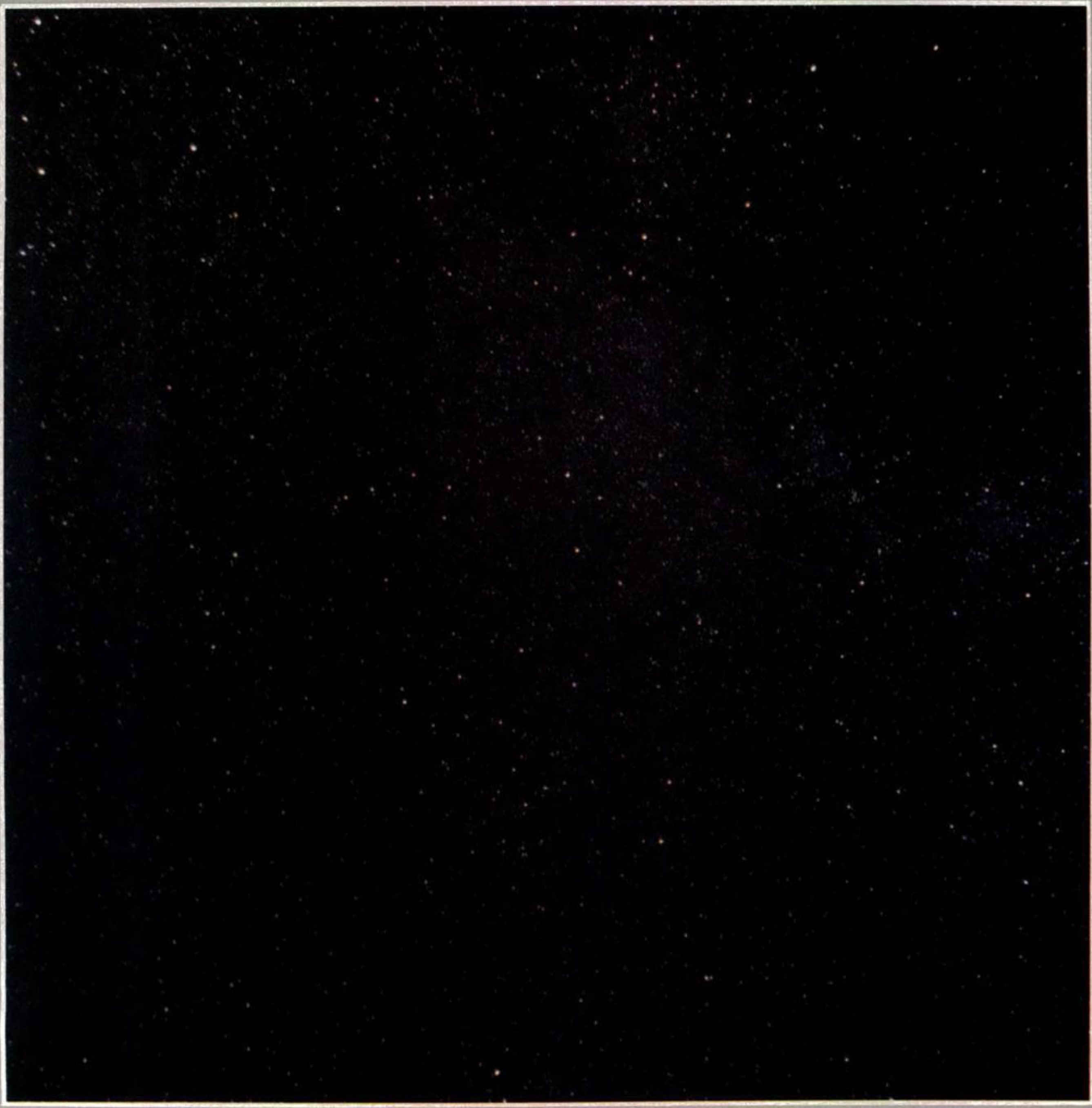
margin, 105 to 82. Thus of all stars brighter than magnitude 3.5, 156 (56%) are found in the southern hemisphere of the sky while only 122 (44%) are found in the north — a margin of 12%. This same margin of the south over the north holds all the way down through the sixth magnitude — there are actually about 800 more stars visible to the naked eye in the southern half of the celestial sphere than in the northern.

Thus an average person standing at the north pole would be able to see about 2600 stars in the sky, but from the south pole he could see about 3400 — quite a few more. Why is this? In other words, why are there about 12-13% more stars in the southern hemisphere than in the northern? Apparently the difference is just due to coincidence — there just happen to be more stars visible from Earth in the southern half of the sky than in the northern.

Moving south from the north pole, we find that at 60° north latitude exactly 50% of the southern celestial hemisphere (25% of the whole sky) never rises above the horizon (the mathematical horizon — we are neglecting such effects as atmosphere refraction). Thus to the 2600 stars in the northern sky we can add about half of those in the southern, for a total of 4300 stars. As we go farther south, the percentage of the whole sky still hidden drops rapidly to about 18% at +50° latitude, 12% at +40°, 7% at +30°, and only 3% at +20° — still well over a thousand miles north of the equator.

Therefore about 1200 stars can never be seen from a latitude of +50°, 800 from +40°, 500 from +30°, and 200 from +20°. So we estimate that about 4800 stars would be visible from +50° latitude, 5200 from +40°, 5500 from +30°, and 5800 from +20°.

But this is the total number of stars the average person could see over a full year. At any particular time on a certain night, of course, fewer will be visible. However we can't simply divide the above numbers by two,



because there are a number of stars — the so-called "circumpolar" stars — which never set and are always above the horizon at all times throughout the year. Assuming that the 2600 stars in the northern celestial hemisphere are evenly distributed, we calculate that there are a little over 900 naked-eye circumpolar stars at +50° latitude, about 600 at +40°, 350 at +30°, and 150 at +20°. Dividing the rest of the stars visible at each latitude (those which rise and set) by two and adding it to the number of circumpolar stars will give us the approximate total number visible at any particular moment. Here we find the variation with latitude is less, ranging from about 2850 stars at +50° to almost 3000 at +20°.

Thus, in most of the continental United States we can expect, if we have average eyes, to see around 2900 stars glittering in the skies above us on an average dark night of good seeing. Of course we know that there actually are many millions of stars out there, too dim to be seen, but the sight of those few thousand is still impressive and humbling enough. Knowing of those millions, Alfred Lord Tennyson wrote, "As this poor earth's pale history runs, / What is it all but a trouble of ants / In the gleam of a million million suns?"

Close-Up

Lacerta

"An obscure group lying between Cygnus and Andromeda containing some fine Milky Way fields" was Muirden's assessment of this month's neglected region. Lacerta, the sky lizard, ranks 68th in size among the 88 recognized constellations, but this stellar wilderness is surely one of the least observed of all such heavenly precincts. Just ask any stargazer what his favorite object is in this region and you'll see what we mean.

True, there are no bright naked-eye stars gracing this region and "real" deep-sky objects are in short supply. With the exception of a handful of open clusters and one tiny, dim planetary nebula, the wonders here are all stellar — visible stars, old novae and double and multiple systems in amazing profusion. Yet the primary attraction and charm of Lacerta is its rich and varied star fields. Calling this figure

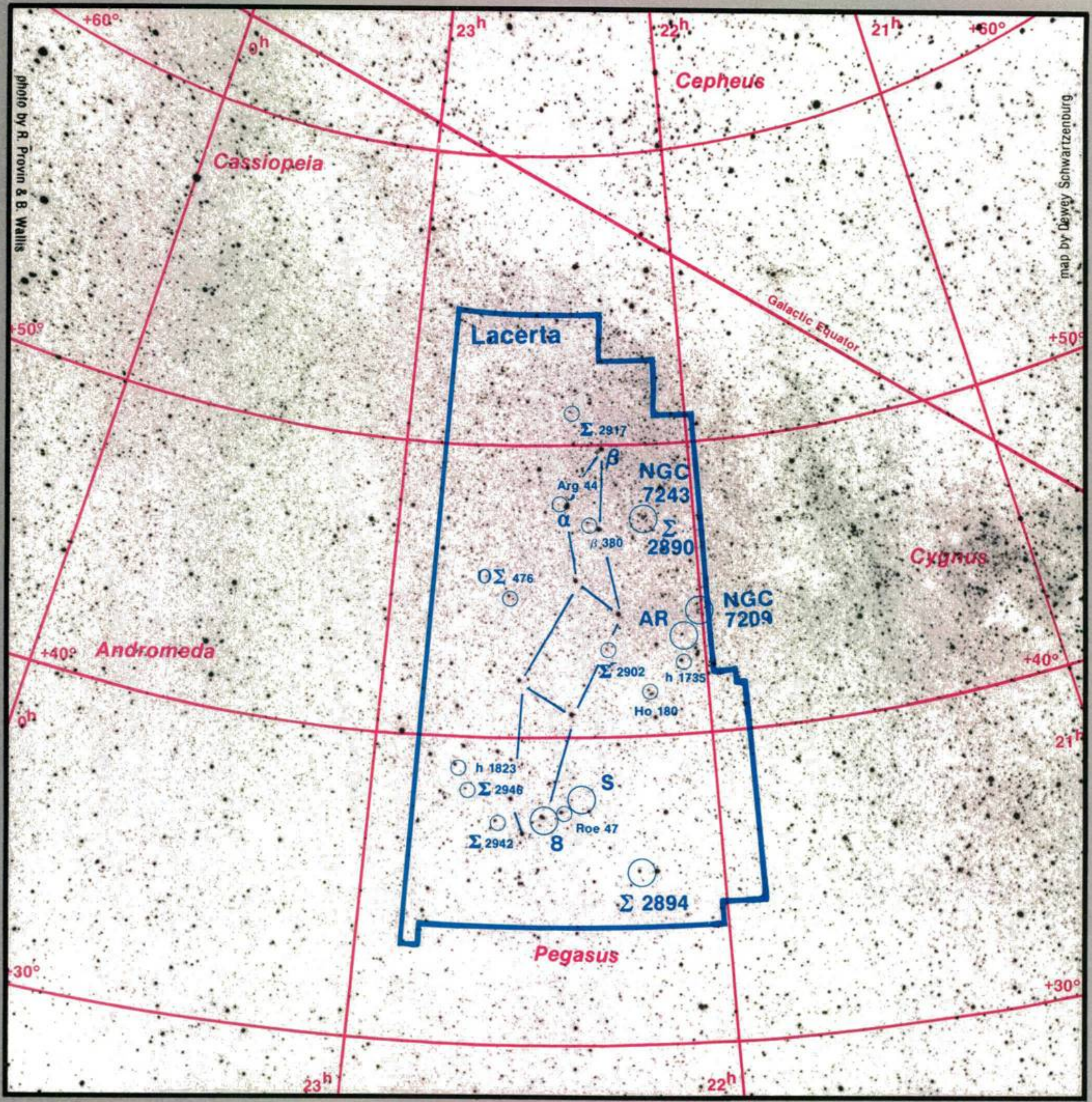


photo by R. Provin & B. Wallis

map by Dewey Schwartzenburg

"a conspicuously placed modern asterism," Barns noted that "though it displays no special units brighter than the fourth magnitude, as an aggregation half enclosed in the Milky Way, it offers a noble field for explorations."

Webb likewise considered Lacerta "a small and not distinctly marked asterism. Glorious sweeping from Cygnus in this direction, and towards head of Cepheus." (The word "not" doesn't appear in the modern Dover reprint of Webb's classic work, but is in the original editions.) He further noted that Alpha Lacertae "points out a noble field. 5 [Lacertae], a 5th magnitude star, 2½° south preceding (west), is a fine object, deep orange, with blue attendant in rich vicinity" and that Beta Lacertae lies "on a glorious field."

The Lacerta region is best appreciated by sweeping across its expanse with a 4 or 6-inch rich field telescope (RFT) at 15 to 25 power on a dark transparent night. Its northern half is buried in the mainstream of the Milky Way — as we scan southward, the density of this stellar forest drops rapidly until we reach the surrounding meadows beyond the Galaxy's borders. Even seasoned observers are sure to be delighted with the richness and diversity of its star-studded fields.

8 Lacertae

The principal telescopic wonder of this month's region is the little-known multiple star system 8 Lacertae. Look for it in a naked-eye splash of stars just above the Pegasus border, some 9° due north of Eta (η) Pegasi. Our target forms a right triangle with 10 and 12 Lacertae as seen in a finder.

Here we find a moderately bright double star made up of 5.8 and 6.6 magnitude suns 22 seconds of arc apart near position angle 185° (or nearly north-south on the sky). Closer inspection will reveal two additional fainter companions — a 10th magnitude one 48 seconds from the primary star in position angle 170° and a 9.5 magnitude one 80 seconds away at 145°. (There are two other even fainter visual members of this complex system, but at 13th and 14th magnitude they lie beyond the grasp of small instruments.)

The bright pair is easily resolved even in a 2-inch at 30 diameters and four stars can be glimpsed in a 3 or 4-inch scope at 45 to 90 power. Larger apertures greatly enhance the overall scene here, as do a steady, transparent night and the use of averted vision.

Smyth recorded the tints of 8 Lacertae's components in his fine 6-inch refractor as "two white, greenish, blue." Webb, using his 3.7-inch refractor, found the "first two white, perhaps tinged with yellow, 10.2 uncertain, 8.5 blue." (Like other observers of his time, he rated this last star a magnitude brighter than the modern value. Has it decreased in luster over the years or is this another example of inaccuracies in early estimates?) Muirden gave the bright pair as both yellowish in hue but made no mention of the fainter stars in his account.

Treating this object along with neighboring Pegasus, Olcott found 8 Lacertae "a fine quadruple star" as seen in his 3-inch refractor, while Barns called it a "double-double — superb!" in his 10-inch reflector. The two bright components are both hot, blue-white B-type suns and the entire clan lies some 1100 light-years from us, set against the sparkling backdrop of our home galaxy. Seldom gazed at, it awaits your inspection the next clear night.

AR Lacertae

An eclipsing variable star similar to, but much fainter than famed Algol in Perseus, is AR Lacertae. Like Algol, AR's changes in brightness can easily be followed in binoculars and small telescopes. Lying just a degree southeast of the open cluster NGC-7209 (see below), both objects are visible in the same finder or RFT field.

AR Lacertae "winks" once every 1.98 days (or very nearly 48 hours), fading noticeably from its normal magnitude of 6.8 to 7.6 over the space of a few hours. Once you've caught it at minimum light, you can compute times of other dimmings by simply adding multiples of the period, omitting those that occur during daylight hours, from your observing location. Surrounding non-variable field stars are used for reference — one nearly matching AR's usual luster lies in a tight group with two brighter stars a degree southwest of the variable itself.

Here, as with other members of its exciting and dynamic class, we are viewing the mutual revolution and occultation of two giant suns (spectral classes G5 and K0) far out in the depths of interstellar space. If you like some "action" in your celestial fare, try catching AR Lacertae in its act over the coming weeks.

S Lacertae

Another of this region's multitude of variable stars — this one a "real" (intrinsic) one rather than merely the result of celestial geometry as with the last object — is S Lacertae. This restless giant is an easy target for binoculars and finders at maximum, but when near minimum light requires at least a 6-inch telescope to be glimpsed. Look for it 2° due west of the star 12 Lacertae and slightly more than a degree northwest of 8 Lacertae.

S Lacertae is a long-period Mira Ceti-type variable whose brightness waxes and wanes between 7.6 and 13.9 magnitude over a period of nearly 240 days. Like most of its kind, it is an M-type giant sun having a distinct ruddy hue throughout its cycle — reminding some observers of an interstellar traffic light or some colossal beating heart. Its color aids in distinguishing it from surrounding field stars, especially at minimum light. Will this fiery beacon be "up" or "down" in brightness during September? This we will leave for you to discover for yourself the next clear moonless night.

Struve 2894

Typical of the large double star population of the Lacerta region is the common proper motion (CPM) pair Struve 2894. This object also happens to be one of the very few members of its class in this region to receive attention from at least some of the noted visual observers of the past. You'll find it near the Pegasus border, some 5° northeast of the obvious naked-eye duo π^1 (Pi-1) and π^2 (Pi-2) Pegasi. It lies just a half degree east of an undesignated star readily seen at 3rd magnitude.

Struve 2894 consists of 6.0 and 8.2 magnitude stars an easy 16 seconds apart near position angle 195°. The components are relatively fixed in both position angle and separation, but no doubt are gravitationally linked as a long-period binary since they are drifting through space together. Attractive in even the smallest telescope, this pair is at its best in 6 to 8-inch instruments at low magnifications.

Webb described the components of Struve 2894 as both "pale white" and "livid" in 1835; a short time later, in 1850, he called them white and ashy or blue. In still later years, other observers found them "decidedly yellow." In Webb's day, dates were usually given along with color estimates since it was suspected back then that this quality might actually change with time. Today, such effects are thought to be largely subjective in nature — the result of differences in color perception from eye to eye, or even the same eye with age. Still, some observers feel the question is an open one, and little has been done in the way of visual color studies of doubles by modern amateurs. Both Norton and Muirden gave the tints here as white and bluish. How do they look to you with your telescope in 1979?

Struve 2894 is just one of a host of

Selected Objects — Lacerta

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
*NGC-7209	○	7.6	20′	22^h02^m	+46°16′
AR	Ӿ★	6.8-7.6	2.0^d	22^h07^m	+45°30′
h 1735	★^{2}	6.9,8.2	27″	22^h07^m	+44°36′
*Σ 2890	★^{3}	8.5,8.5,9.5	9″,73″	22^h13^m	+49°38′
*NGC-7243	○	7.4	20′	22^h13^m	+49°38′
Ho 180	★^{2}	7.0,7.0	0.7″	22^h14^m	+43°39′
*Σ 2894	★^{2}	6.0,8.2	16″	22^h17^m	+37°31′
Σ 2902	★^{2}	7.0,8.0	6″	22^h21^m	+45°06′
β 380	★^{2}	7.5,8.0	36″	22^h25^m	+49°27′
*S	m★	7.6-13.9	240^d	22^h27^m	+40°04′
Σ 2917	★^{2}	8.0,8.0	5″	22^h29^m	+53°16′
Roe 47	★^{5}	5.8,10.2,10.5, 9.5,10.0	42″,32″, 106″,7″	22^h30^m	+39°31′
Arg 44	★^{2}	8.0,8.0	7″	22^h32^m	+50°07′
*8	★^{4}	5.8,6.6,10.2, 9.5	22″,48″, 81″	22^h34^m	+39°23′
OΣ476	★^{2}	7.0,7.4	0.5″	22^h41^m	+46°54′
Σ 2942	★^{2}	6.3,8.5	3″	22^h42^m	+39°12′
Σ 2946	★^{2}	8.0,8.0	5″	22^h47^m	+40°15′
h 1823	★^{4}	6.5,7.5,7.5, 9.0	82″,119″, 5″	22^h50^m	+41°03′

*Detailed in Close-Up

★ *Star*	m★ *Regular Variable*	○ *Open Cluster*	§0 *Elliptical Galaxy*
★· *Bright Star*	n★ *Irregular Variable*	● *Globular Cluster*	§S *Spiral Galaxy*
★: *Double Star*		■ *Planetary Nebula*	§ʃ *Barred Spiral Galaxy*
★⁝ *Triple Star*	Ӿ★ *Eclipsing Variable*	□ *Bright Diffuse Nebula*	§# *Peculiar/Irregular Galaxy*

double and multiple stars scattered across Lacerta from the catalogs of the Struves, the Herschels, Argelander, Hough, Burnham, Aitken, and other great observers of the past. If this stellar duo turns you on, why not seek out more of its kind from our table of selected objects? As you'll soon discover to your own surprise and delight, no two of these tinted jewels of the sky are exactly alike.

NGC-7243 & Struve 2890

The best of Lacerta's open clusters is our next offering: NGC-7243. It is easily swept up with a low power eyepiece on the telescope just 2° west and slightly south of Alpha (α) Lacertae — it forms a squat triangle with that star and nearby 4 Lacertae to the southeast as seen in a finder or binoculars.

This stellar commune contains some 40 or so member suns spread over an area 20 minutes in extent, and glows with the combined light of a 7th magnitude star. Although classified as "loose and poor" as open clusters go, it is nevertheless a fine sight on a dark night in 4 to 8-inch telescopes at low to medium powers.

Discovered by Sir William Herschel during his epic sweeps of the heavens from England, NGC-7243 also carries his designation HVIII-75 (or H75^{8} in some atlases like Norton's). This indicates it is the 75th entry in his class VIII — coarsely scattered clusters of stars. **The New General Catalogue (NGC)** describes it as a "cluster, large, poor, little compressed, stars very large (bright)," and Brown gave the stars here as 9th to 14th magnitude in individual brightness.

Webb called this object a "fine cluster, quickly followed by beautiful field with 3 pairs" and Chambers "a magnificent field of stars." Muirden saw it as "a bright cluster set in a rich region" and Norton "a fine, open, irregular cluster, followed by a beautiful field." And finally, as seen in his 10-inch homemade reflector from the clear skies of California half a century ago, Barns logged this clan as "massed star-jewels."

An added feature of interest to telescopists here is the rather faint but attractive triple star Struve 2890. This trio of 8th and 9th magnitude suns has separations of 9 and 73 seconds, and lies in the same eyepiece field as the cluster. While a 3-inch glass at 45 to 90 power shows this object well, both it and the cluster benefit greatly by the increased light grasp of 6-inch and larger apertures.

Like its host constellation, NGC-7243 seems little-known to most modern deep-sky enthusiasts. Yet seen against the sparkling backdrop of the Milky Way on a dark, transparent night, this remote swarm of fireflies is a fascinating sight sure to delight the visual senses. Its muted photon emissaries arriving here tonight left the cluster on their vast journey earthward over 25 centuries ago — surely some star-lover should be on hand to greet them.

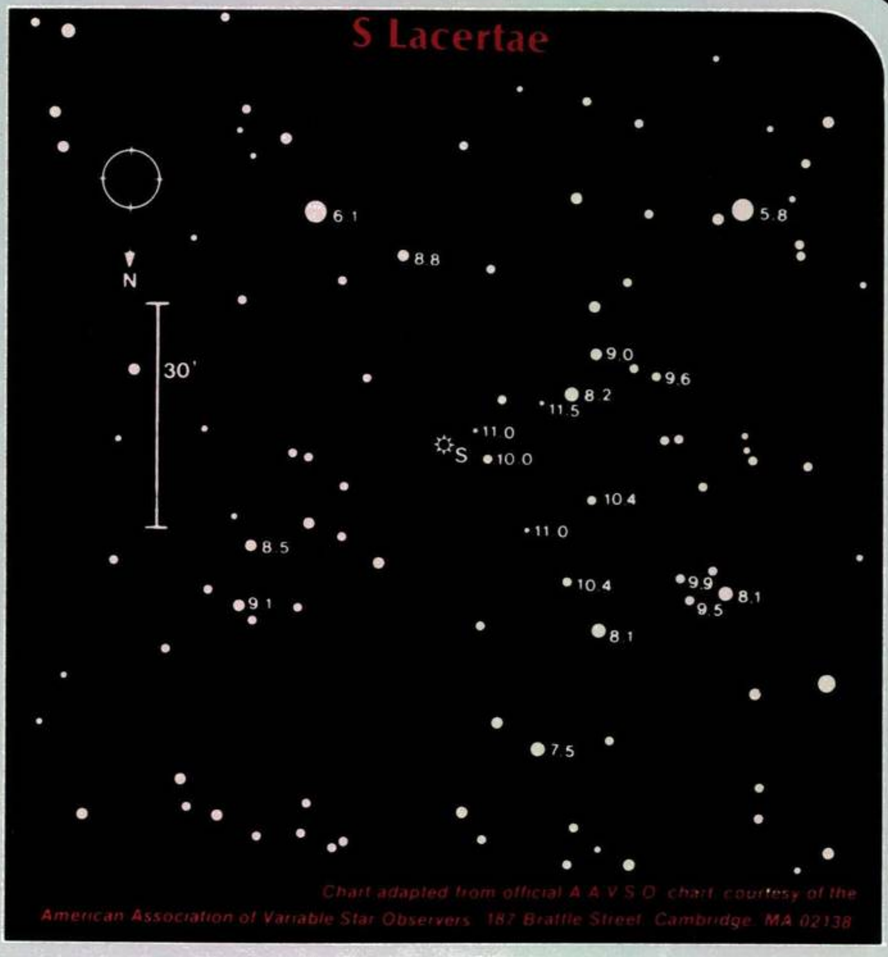


Chart adapted from official A.A.V.S.O. chart, courtesy of the American Association of Variable Star Observers, 187 Brattle Street, Cambridge, MA 02138

NGC-7209

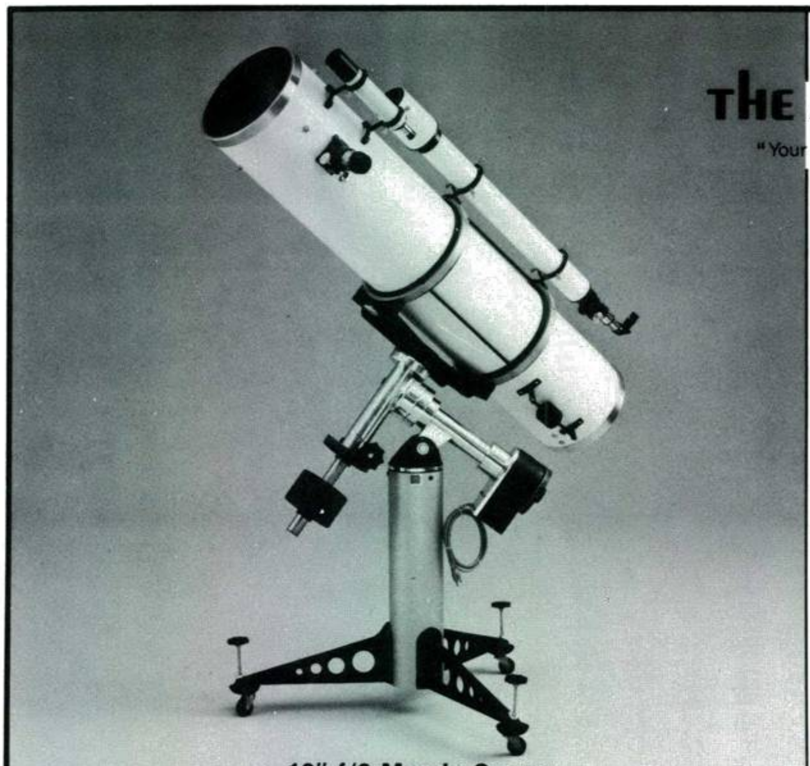
Our final stop in Lacerta is another open cluster — one that the published catalog data would lead us to believe is identical in visual appearance to our last object. Here's an ideal demonstration of the fact that such parameters alone cannot provide a reliable index to what will be seen at the eyepiece, or the relative visual appeal of one deep-sky object compared to another.

Our case in point is NGC-7209 — another of William Herschel's many finds bearing his designation HVII-53 (or H53^{7} — the 53rd entry in his class VII, compressed clusters of small and large stars). Look for it in your finder about 4° southwest of NGC-7243, at the Cygnus-Lacerta border. A 3 or 4-inch scope shows it nicely at 45 power on a dark night.

Checking the catalog values, NGC-7209 has nearly the same brightness (7.6 magnitude), size (20 minutes of arc), number of stars (50) and classification (loose and poor) as NGC-7243. Yet they look quite different at the eyepiece — something you might like to check for yourself the next clear night.

The **NGC** describes its 7209th entry as a "cluster, large, considerably rich, pretty compressed, stars from 9th to 12th magnitude." Little else is to be found in the literature about its telescopic appearance. Indeed, a definite lack of descriptive visual impressions exists for all of this month's region. Even Robert Burnham, Jr. in his vast and exhaustive **Celestial Handbook** gives only a single descriptive entry under Lacerta (and that for a nova). This lack offers an ideal opportunity for modern observers to fill a gap in the observational literature with eyewitness accounts of their own. As a start, you might plan to log your visual impressions of all these entries in the accompanying table lying within reach of your telescope.

William James once remarked that "The greatest use of life is to spend it for something that will outlast it." Surely, rendering and preserving for others to enjoy the appearance of overlooked and neglected wonders of the night sky would — albeit in a small way — satisfy this inspired and lofty ideal.



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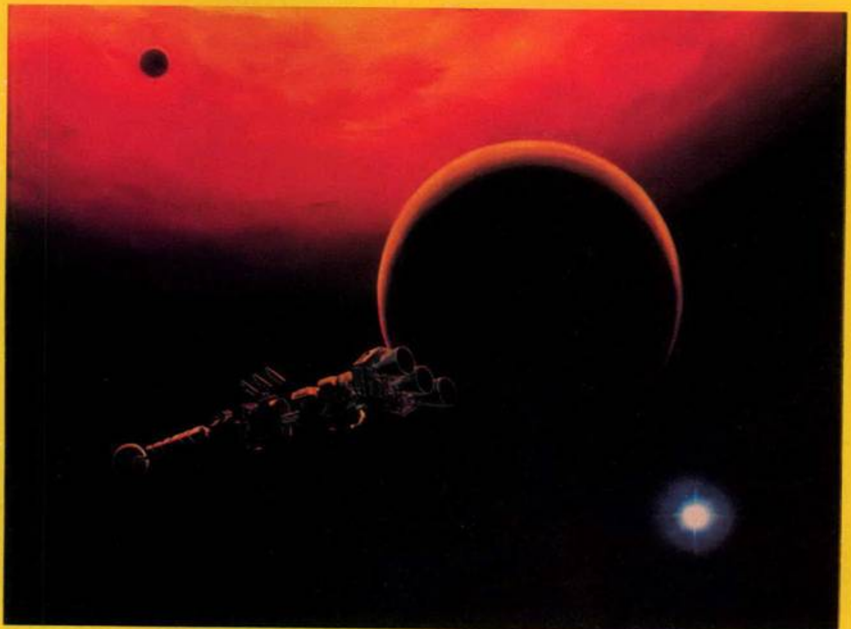

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